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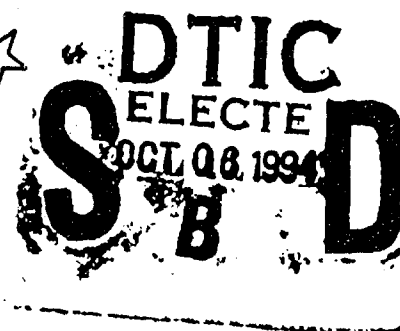
THE EFFECT OF VIOLATIONS
OF THE CONSTANT DEMAND
ASSUMPTION ON THE
DEFENSE LOGISTIC AGENCY
REQUIREMENTS MODEL

THESIS

William S. Long, Captain, USAF
Douglas H. Engberson, Captain, USAF

DEPARTMENT OF THE AIR FORCE
**AIR UNIVERSITY**

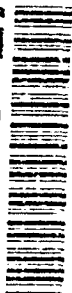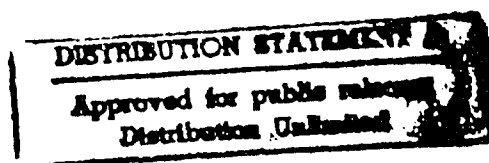# AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AFIT/GLM/LAL/94S-15

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and do not reflect the official policy or position of the
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THE EFFECT OF VIOLATIONS OF THE CONSTANT

DEMAND ASSUMPTION ON THE DEFENSE LOGISTIC

AGENCY REQUIREMENTS MODEL

THESIS

Presented to the Faculty of the Graduate School

of Logistics and Acquisition Management of

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In Partial Fulfillment of the

Requirements for the Degree of

Masters of Science in Logistics Management

William S. Long, B.S.  Douglas H. Engberson, B.S.
Captain, USAF  Captain, USAF

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## Acknowledgments

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## Abstract

This project determined the impact of stationary but
non-continuous demand levied in a multi-echelon system.
Specifically discussed is how this "lumpy" demand affected
the Defense Logistics Agency, Defense Electronics Supply
Center in its computed inventory levels and total variable
costs.

To determine the impact of "lumpy" demand, data were
extracted from the Defense Logistics Supply Center and,
based on patterns of demand distributions, the authors
constructed a SLAM II model that depicted "lumpy" orders
being received at the Defense Logistics Agency.

The SLAM II model was built for the proposed system and
simulation runs were conducted using demand distributions
gathered from the sample data set. These runs indicate that
"lumpy" demand does impact total variable cost and on-hand
inventory.

The authors recommend The Defense Logistics Agency
consider another lot sizing technique or look into a
Distribution Resource Planning model to improve overall
system inventory levels and total variable cost.

# THE EFFECT OF VIOLATIONS OF THE CONSTANT DEMAND ASSUMPTION ON THE DEFENSE LOGISTIC AGENCY REQUIREMENTS MODEL

## I.  Background and Problem Presentation

### Introduction

The multi-echelon environment, "when production is separated from consumption by several echelons" (Tersine, 1994: 458), presents unique characteristics that must be considered when choosing an appropriate inventory policy for an elevated echelon.  The policy chosen for one level influences supply decisions at each level of the logistics network and the influence becomes amplified from one echelon to the next (Tersine, 1994: 458).  It is therefore important to understand explicitly how a chosen policy functions in relation to the policies of other levels.  This understanding could allow an inventory policy decision to be made at one level that improves overall system performance. A more detailed analysis of the researched system is presented below.

### The Conceptual Model

Major Nathaniel Robinson summed up the Defense Logistics Agency (DLA) and its importance to the Air Force when he wrote the following:

The Defense Logistic Agency (DLA) is the largest wholesaler of consumable items in the Department of Defense (DOD). The Air Force logistic community's capabilities and operational readiness -- insofar as DLA-managed items are concerned -- are directly proportional to its knowledge and use of DLA support programs. (Robinson, 1993: xvii)

Table 1 demonstrates the extent of DLA's presence in the supply of consumables to DOD by showing the number of national stock numbers (NSNs) associated with weapon systems that are managed by DLA for each Service.

Table 1.
Weapon System National Stock Number Stratification by Service (First Quarter Fiscal Year 1992)

| Army | Navy | Air Force | Marine Corps | Totals |
|------|------|-----------|--------------|--------|
| 281,519 | 771,263 | 459,487 | 27,006 | 1,539,275 |

(Robinson, 1993: 17)

Due to concern for the "logistic community's capabilities and operational readiness," as mentioned by Maj. Robinson above, and the volume of NSNs handled by DLA, military logisticians should understand the inventory policies and models used by DLA to support its customers. How these policies and models react to the inventory policy used by customers should also be an important concern. In particular, Air Force logisticians need to be concerned with the effect base level supply policy has on the supply policy used by DLA.

The inventory policy currently used by DLA is a hybrid of Wilson's Economic Order Quantity (EOQ) model, coupled

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with a variable safety level (Balwally, 1994: Interview).
Wilson's EOQ model and the hybrid EOQ model used by DLA both
seek to minimize total variable cost by balancing holding
cost with ordering cost.

Certain assumptions about the demand, replenishment,
and time elements of the system must be made in order to use
these models. These assumptions are provided in Table 2.

Table 2.

Assumptions Required by Wilson's Classic Economic
Order Quantity Model

---

1. The demand rate is known, constant, and continuous.
2. The lead time is known and constant.
3. The entire lot size is added to inventory at the same time.
4. No stockouts are permitted; since demand and lead time are known, stockouts can be avoided.
5. The cost structure is fixed; order/setup costs are the same regardless of lot size, holding cost is a linear function based on average inventory, and unit purchase cost is constant (no quantity discounts).
6. There is sufficient space, capacity, and capital to procure the desired quantity.
7. The item is a single product; it does not interact with any other inventory items (there are no joint orders).

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(Tersine, 1994: 95)

While these assumptions are necessary to develop the
models, they are not always realistic. Violations of the
EOQ model assumptions frequently occur under normal business
operations. "A situation can rarely be found where both
demand and costs are known precisely and where demand is

truly constant" (Tersine, 1994: 102). One question to be asked then is: What effect does violating the constant and continuous demand assumption have on an EOQ inventory policy?

Figure 2 shows the difference between available inventory in a system that holds to the assumptions for EOQ and one where the demand rate and lead time assumptions are violated.
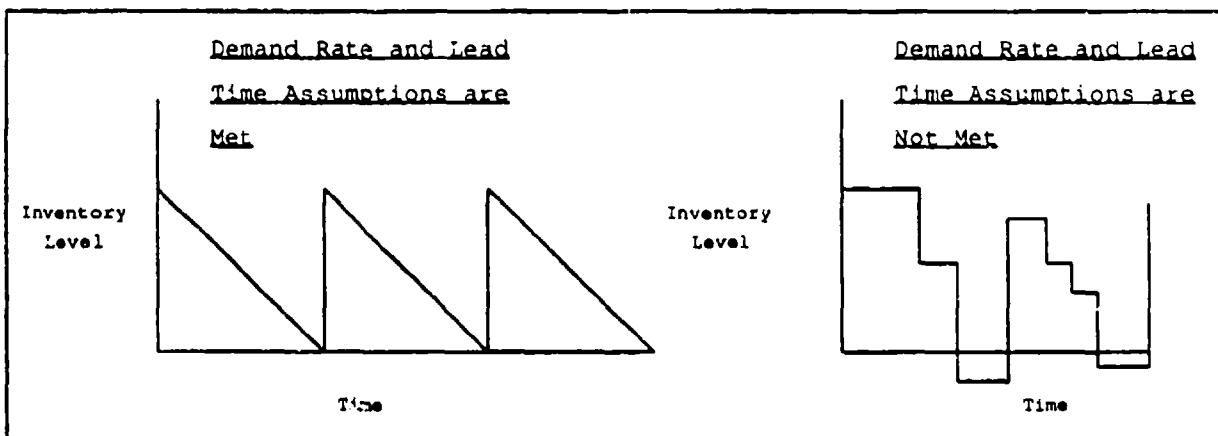


Figure 1. Comparison of "Model with Assumptions Met" with "Model with Assumptions Not Met" (Adapted from Tersine, 1994: 93, 207)

Violation of the assumptions can lead to negative inventory levels. These points, represented by points below the time axis in the right graph of the figure above, indicate that backorders can occur. This research will target the EOQ model where demand rate and lead time assumptions are violated and the effect on inventory level will be used as measures of effectiveness.

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## Problem Statement

The problem is to identify the effect an economic order quantity policy has when it is used under non-continuous demand pattern conditions on inventory levels and total variable costs. In particular, DLA uses an EOQ type approach to manage inventory at the second echelon of a multi-echelon system (Balwally, 1994: Interview).

Echelons are levels within the consumable item system. The first echelon is the lowest level, base level. The second level is the distribution center. In this study the second echelon is represented by DLA. The highest level or echelon of this system is the vendor supplying consumable items to DLA.

Order size and timing is not constant or continuous at the second echelon and yet the model used assumes constant, continuous, and known demand and lead time (Blazer, 1986: 1). The effect of these assumption violations should be considered by DLA and DOD inventory policy managers.

Consumable item demand at Air Force bases is rarely constant or continuous. "Air Force demand patterns tend to be 'lumpy' and erratic" (Blazer, 1986: 1). Demand is known to some extent from the law of averages, but the exact size and timing of each request for a specific consumable is not known. Because demand for individual items is not constant or continuous, the orders placed on DLA for base replenishments are neither constant nor continuous. In

fact, considering DLA provides support to multiple Services and multiple activities within those Services, the variation on order timing and size is compounded in a much more complex fashion than may be encountered at a base. DLA experiences increased variation in demand because it has to deal with the aggregate demand variation from each activity. This is the ripple effect of amplified influence among echelons that was described earlier.

Further, base stock levels are determined using an economic lot sizing ordering policy that prevents demand from being levied on DLA in a continuous manner (Military Logistics, 1990: 7-6). This lot-sizing method is the EOQ inventory policy and it places "lumpy" demand on DLA. The addition of lead time variation to the system compounds the problem further by yielding greater variation in order size and timing (Blazer, 1986: 12).

## Research Objectives

The purpose of this research is to investigate the impact of demand rate and lead time assumption violations on the EOQ model used by DLA to support Air Force consumable requirements. The specific objectives for the research include:

1. Establish the performance measures of total variable cost and inventory levels at DLA, as appropriate for

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determining the effects of "lumpy" demand on DLA's EOQ
model.

2.   Gather and evaluate data from the Defense
Electronics Supply Center (DESC) to produce acceptable
ranges of input factors for simulation purposes.

3.   Perform a simulation for DLA's EOQ model to yield
the necessary output to measure "lumpy" demand effects.

## Research Questions

To achieve the goals set forth in the listed
objectives, specific questions have been prepared for
research.  These research questions are:

1.   What impact does violation of the demand rate and
lead time assumptions have on DLA's EOQ model?

2.   How does DLA's EOQ model effect total variable cost
at the distribution center under "lumpy" demand conditions?

3.   How does DLA's EOQ model effect inventory levels at
the distribution center under "lumpy" demand conditions?

## Hypotheses

Tests of hypotheses will be performed to respond to the
research questions.  Comparisons of simulation model output
will be made based on the statistical results of the
hypothesis testing.  In particular, the hypotheses to be
tested will include:

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*Null Hypothesis 1.* Total distribution center variable costs for DLA's EOQ model are the same regardless of the characteristics of the items handled by the model.

*Alternative Hypothesis 1.* Total distribution center variable costs are different for at least one set of item characteristics.

*Null Hypothesis 2.* Expected distribution center inventory levels for DLA's EOQ model are the same regardless of the characteristics of the items handled by the model.

*Alternative Hypothesis 2.* Expected distribution center inventory levels are different for at least one set of item characteristics.

## Methodology Overview

The tool used in this research is simulation. Simulation has been determined to be the most appropriate evaluation instrument because the goal is to imitate reality, not report on reality or constrain reality to narrowly defined assumptions (Law, 1982: 8). Modeling by simulation also provides a low cost, low risk, well-controlled means of studying the effects of various inputs to a system (McFeely, 1993: 4-2). Likewise, the research examines how the model performs when certain assumptions that go along with it are violated.

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> What should you do when the characteristics of an inventory
> system do not appear to agree with the assumptions of any
> inventory decision model?  In this case, there are two
> alternatives: (1) attempt to develop and use a specifically
> designed decision model that correctly reflects the
> characteristics of the system, or (2) attempt to develop and
> experiment with a computer simulation model that will
> indicate the impact of various decision alternatives on the
> cost of operating the system. (Evans, 1993: 484-5)

A comparison of means will be accomplished using
results from a SLAM II simulation model developed by the
researchers.  An analytical model, as necessary for using
Evans first alternative, would have to be complex to account
for the assumption violations.  This statement by Evans and
the researchers desire to investigate the violation of
assumptions would indicate that an analytical model would be
impractical.  Simulation provides latitude to relax
assumptions and to evaluate models not currently in place
(Tersine, 1994: 508-9).

## Scope

Evaluating the current inventory policy used at the
centralized distribution centers in the military multi-
echelon *consumable* requirements system is the focus of this
research.  A consumable item is "an item that is normally
expended or used up beyond recovery in the use for which it
was designed or intended" (Pohlen, 1993: notes).
Specifically, the methods used by the Defense Logistics
Agency (DLA) for satisfying consumable requirements will be
addressed.  DLA is the supplier of consumable items to the

Department of Defense (DOD), as well as other government agencies.

The system of interest for this research consists of the following key players: Air Force bases at the first echelon, DLA distribution centers at the second echelon, and contractors and vendors at the last echelon. Figure 1 is the graphical representation of the researched system.
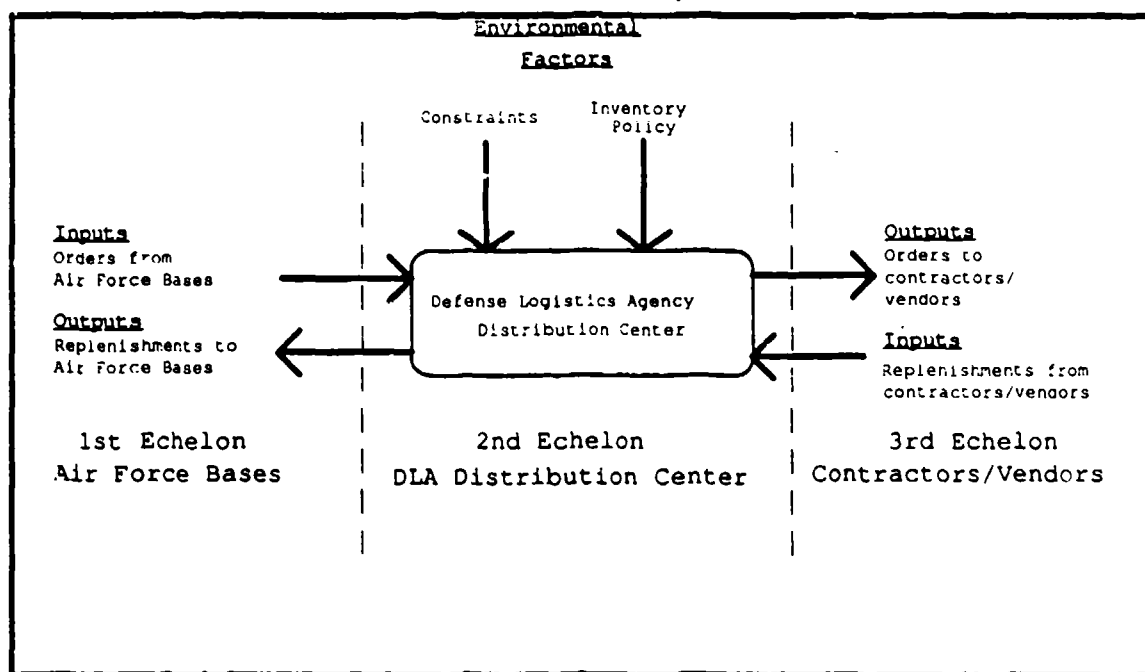


Figure 2. Model of the Air Force Consumable Requirements System

From this system perspective, the management factor that can be controlled and modified is the inventory policy at the distribution center level.

The scope of this research is to examine the effects of "lumpy" demand on distribution centers belonging to DLA. Data gathering has been limited DESC. The use of DESC data

provides a representative sample of DLA NSNs by presenting
items with differing characteristics. Samples were gathered
with the aid of DESC "experts," Mr. Balwally and Mr.
Bilikam, to ensure that a variety of item characteristics
are researched. Therefore, results from the simulation can
be generalized to all DLA distribution centers (Personal
interviews, 1994).

## Assumptions

Certain assumptions must also be made in developing
this research. First, an assumption must be made that the
sample of data used for research is representative of the
population of all consumable items. Considering the multi-
echelon environment of the system, the researchers assume
that at the base level, a lot-sizing model is used to place
demands on DLA. This assumption is made because base level
demands are not modeled in the simulation and are outside
the scope of this study.

Assumptions must also be made within the examined
models. DESC uses established ordering and holding costs.
The researchers assume these costs have been accurately
determined. DESC also has an incorporated forecasting
method built into its inventory model. The effect of the
forecasting procedure on the inventory model is beyond the
scope of this research. An assumption is made that the
forecasting method is appropriate for its intended purpose.

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Further, an assumption is made that there are no budgetary or warehouse constraints that would influence order quantities. Price break quantity or consolidated orders are not allowed.

## Limitations

As previously mentioned, the data used for the simulation model was compiled solely from the Defense Electronics Supply Center (DESC). This limitation was imposed due to time and the financial constraint of traveling. As such, the researchers allowed DESC analysts to obtain an appropriate range of data for the representative sample. Another limitation is that the data gathered from DESC is limited to items used by the Air Force only. Further, only EOQ managed items were included in the sample. DESC does not manage all items under the EOQ policy. Some items are under the Non-Stockage Objective (NSO) program. NSO consumables do not have sufficient demand to effectively use the EOQ model. (Balwally, 1994: Interview)

## Management Implications

The goal of this study is to determine the impact of "lumpy" demand on inventory levels and total variable cost under DLA's EOQ method. Managers should always be interested in providing optimal support at the lowest cost.

It is also true that the feasibility of the results must be considered. For example, it would be impractical to suggest changing a system to save $100 per year when the cost of the change is $1,000,000. The conclusion section of this research will address the implications of "lumpy" demand on inventory levels and total variable costs at DLA. It is the visibility of these tradeoffs that should most benefit managers evaluating this study. Should the findings show that "lumpy" demand does cause significant changes in total variable cost and inventory levels when using an EOQ type approach, management should be influenced toward finding a better inventory model for handling the unique requirements of "lumpy" demand. The researchers expect that a better inventory technique, such as Distribution Requirements Planning, might be a probable alternative but reserved for future research. At any rate, management behavior should be shifted to focus on the effects that inventory models have on cost and support when considered along with the assumptions that must be made to implement them. All models work within a system and managers need to take a system perspective when analyzing them.

## Organization of Research

Chapter 1 has introduced the concept of "lumpy" demand and showed how this situation occurs between base level supply and DLA distribution centers. An overview was given

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of the research plan to address the impact of this situation. Also, management implications were presented to show why DOD and DLA managers should review this study.

In Chapter 2, the purpose of holding inventory, types of inventory, and the history of Air Force consumable management will be presented. Also, a detailed analysis of Wilson's Classic EOQ model and the current DLA EOQ model will be given.

Chapter 3 lays the groundwork for the experiment to be carried out by describing the detailed research methodology. A simulation model will be presented and the plan for gathering and analyzing data will be shown.

Chapter 4 presents the data output from the simulation model, the analysis of this data, and the results of experimental design tests conducted on the data. Hypotheses proposed in Chapter 1 will be rejected or not rejected based on the output data and a foundation will be formed for conclusions and recommendations.

In Chapter 5, conclusions are drawn from the data results of Chapter 4. Results are examined and suggested for implementation. Possible future research topics in the problem area will be submitted by the researchers.

## II. Literature Review

### Overview

It is important to understand the current ordering process DLA uses to manage inventory before discussing the effects that "lumpy" demand may have on the system. Consequently, a review of literature is presented to establish an understanding of inventory management practices. This review first details why inventory is traditionally held, including the primary purposes and main reasons for holding inventory. Air Force consumable inventory management policy is then discussed detailing the evolution of consumable inventory management. Next, Wilson's classical Economic Order Quantity inventory model and formula is addressed. The EOQ inventory model is used as a basis for inventory management both in the Air Force and at the Defense Logistics Agency.

DLA is presented as the major supplier of consumables to the Department of Defense. However, it is from the Air Force point of view that the interface with DLA will be addressed. Included in the review is the DLA model for consumable inventory management as currently used. An explanation of stationary but non-continuous demand referred to as "lumpy" demand is given last to introduce possible problems associated with the EOQ methodology used by DLA when this "lumpy" condition exists.

## Primary Purposes of Inventory

Inventory is commonly held to accomplish the following four objectives: 1) provide economies of scale, 2) eliminate discontinuity, 3) overcome uncertainty in demand and allow for unanticipated events, and 4) reduce the time it takes a manufacturer to supply goods to its customers (Evans, 1993: 410-412). Objective one, economies of scale, concerns the quantity of inventory a customer might buy. Bulk purchasing can often allow quantity discounts and lower costs.

The second objective, to eliminate production discontinuity, refers to the use of buffer stock between processes. "The discontinuity factor permits the firm to schedule many operations at a more desirable performance level than if they were integrated dependently" (Tersine, 1994: 7). An Air Force example of product discontinuity inventory is the use of bench stock by maintenance personnel. Bench stock is a buffer stock of screws, nuts, bolts, and so forth held in special bins near the maintenance area. This inventory facilitates daily, routine maintenance use of items without orders being processed for each individual demand of these materials (AFR 67-1 Vol. II Part 2).

Third, inventory can be held to overcome shipping time variation, demand variation, and unforeseen events which might halt production. War Reserve Materials (WRM) are held by military organizations in anticipation of a conflict.

WRM is an example of inventory held as safety stock to overcome the unforeseen event of war. WRM is also used to overcome demand and ship time variation occasionally through WRM withdrawals (AFR 67-1 Vol. II Part 2).

The last objective attained through the use of inventory allows finished goods to continually flow through the production line, thereby making the duration of the production process a transparent link in the total time it takes for a customer to receive a product (Tersine, 1994: 6-7). Reducing the time it takes a manufacturer to supply goods to its customers is the reason the Defense Logistics Agency holds inventory for the military services. By ordering and maintaining inventory, DLA in essence absorbs the vendor's production time by holding inventory, allowing inventory to flow transparently to its customers (Robinson, 1993: 5-7).

There is a cost associated with holding inventory, and because of this holding cost, it is beneficial to hold as little inventory as possible and still be responsive to customer demand (Tersine, 1994: 6-9).

Inventory held is usually designated for specific purposes. These purposes to carry inventory can be divided into six classifications: (Tersine, 1994: 7-9).

1) Working stock is held for normal customer demands or business production operations. It is normally located in the organization and readily accessible.

2) Anticipation stock is maintained to handle seasonal demands or for wartime needs in the military case. Anticipation stock is also readily available but stored for planned or known future 'anticipated' requirements.

3) Safety stock is maintained to account for disruptions of supply and variations in demand that are not anticipated but can be forecasted. The amount of safety stock held depends on how critical a shortage would be to the organization.

4) Pipeline stock accounts for demands that occur while an organization waits to receive replenishment from a supplier. Pipeline stock is calculated by forecasting the projected requirements due to transportation time and counting out the amount of stock needed to cover the "lead time" delay.

Time needed for the transportation of an order is referred to as the lead time. "Lead time is the amount of time between the placement of an order and its receipt" (Evans, 1993: 413). Lead times can be as simple as the time required to take a part off the shelf or as complex as engineering or designing an item, fabricating it, and then shipping it.

5) Decoupling stock is held when more than one production activity is dependent on inventory but cannot depend on stock levels of the other activity. Decoupling is often required by geographically separated production

activities that are dependent on raw materials from a central warehouse.

6) Psychic stock increases visibility of inventory and is used in promoting sales. A large display in the aisle of a grocery store is an example of this type of inventory (Tersine, 1994: 7-8).

Thus, inventory is held to maintain sufficient levels of required materials on hand or in the pipeline as needed by any business operation. Just as inventory is needed in any business, it is needed in the Department of Defense.

## Air Force Consumable Inventory Management Theory

Air Force inventory management began the same time the Air Force did.

> The history of Air Force inventory management goes back to World War I. It was during the war that the United States Army Air Service first established a number of aviation supply depots to support its growing air operations. (Air Force Tire Program, 1994: 3)

Since 1918, the Air Force has grown considerably, as has its inventory. Until the 1950s, the Air Force managed its inventories using heuristics (Coile, 1974: 13-6). Purchasing policies for consumable items were based primarily on the dollar value of the item and the quantity to be purchased (Shields, 1982: 5). With the advent of computer automation, however, the amount of information that

could be maintained, managed, and processed greatly increased. In 1954, the Air Force purchased its first UNIVAC computer (Air Force Tire Program, 1994: 4). The computer, coupled with a 1958 RAND study on the potential of implementing an EOQ model within the DOD environment, led to DOD's eventual adoption of an EOQ policy for consumable assets (Shields, 1982: 7-8). Subsequently, in 1958, the Department of Defense drafted and issued Department of Defense Instruction (DODI) 4041.11, Peacetime Operating and Safety Level of Supply. "This instruction directed all DOD activities to use EOQ principles in determining and maintaining [inventory] levels" (Air Force Tire Program, 1994: 8).

"In 1968, the Assistant Secretary of Defense (Installations and Logistics) initiated a review of order quantity determination throughout the DOD" (Bental, 1993: 12). As a result of this review, DODI 4140.39--Procurement Cycles and Safety Levels for Secondary Items--was published in 1970. This manual:

> establishes policy for determining procurement cycles and safety levels of supply at Inventory Control Points (ICPs) for non-reparable secondary items [Consumables] and illustrates the basic mathematical functions and their application in an inventory model that are to be used. (Bental, 1993:1)

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DODI 4140.39 defined the mathematical relationships of the principle components in DOD's adaptation of the classic EOQ model.

As in Wilson's EOQ, the model in DODI 4140.39 is based on the premise that holding costs should be balanced with ordering costs (DODI 4140.39, 1970: Policy Sec V Part a). Holding costs for DOD are comprised of "those costs associated with the cost of capital, inventory losses, obsolescence, storage, and other variable costs of maintaining an inventory" (Bental, 1993: Enc. 4: 1). Ordering costs are defined as follows:

> Costs to be considered in determining cost to order will be those variable direct labor and support costs which begin with the output of the requirement notice, through the mailing of the contract or order and will also include processing the physical asset into the proper warehouse location after receipt from the contractor. Average contract administration cost will also be a part of the cost to order an item of inventory. (Bental, 1993: Enc. 3: 1)

The stated objective of DODI 4140.39 is "to minimize the total of variable order and holding costs subject to a constraint on time-weighted, essentiality-weighted requisitions short" (Bental, 1993:2). This objective is achieved as a result of balancing the ordering and holdings costs of an item under the given constraints of mission essentiality, item criticality, and quantity computed.

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Air Force Military Command Regulation (AFMCR) 57-6 was developed as a result of DODI 4140.39. This regulation provides uniform guidance to Air Force personnel for computing EOQs for wholesale replenishment requirements of consumable items. In addition, AFMCR 57-6 serves as a users guide to understanding the operations and outputs of the DO62 EOQ Requirements Computation System. "The DO62 system takes into account certain economic factors to ensure that items are bought in the most economical quantities possible" (Chatterton, 1994:8). In contrast to the definition of ordering costs as outlined in DODI 4140.39, AFMCR 57-6 defines ordering and holding costs as:

> Cost to order includes costs for Automated Data Processing, personnel, and other administrative costs associated with·Purchase Request (PR) processing and contract negotiation. Cost to hold includes capital costs associated with asset storage and losses due to obsolescence and other causes. (Chatterton, 1994: 9)

Program logic for DO62 is geared to produce a buy quantity that includes an EOQ and projected demands. Furthermore, the DO62 constrains the buy quantity by limiting the purchase quantity to no more than two years of stock. Conversely, a lower bound is established which includes the "demands throughout the administrative lead time or six months' demands, whichever is less" (Chatterton, 1994: 9). DO62 is governed by DODI 4140.39. DODI 4140.39 constrains the buy quantity to no more than

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three years--and no less than three months--worth of stock
(DODI 4140.39, 1970: Encl. 2-3). This becomes a limit to
DLA when using the EOQ model, as the EOQ might yield a
result above or below this constraint.

Because DLA's model is based on the classic EOQ model,
it is necessary to discuss the classic EOQ model. The use
of the EOQ model has improved the Air Force's management
procedures compared with the heuristics used earlier (Coile,
1974: 12-35).

## Classical EOQ Inventory Model

The EOQ concept was first introduced by F.W. Harris in
1915 (Hadley, 1963: 30) and developed by Edwin Bidwell
Wilson, for whom the model is named (Eatwell, 1987: 922-3).
The classical inventory model, commonly referred to as a
sawtooth diagram due to the pattern of demand (Figure 3.),
is a starting point for traditional inventory management.

Q = Lot size
ROP = Reorder point
ac = ce = Interval between orders
ab = cd = ef = Lead time
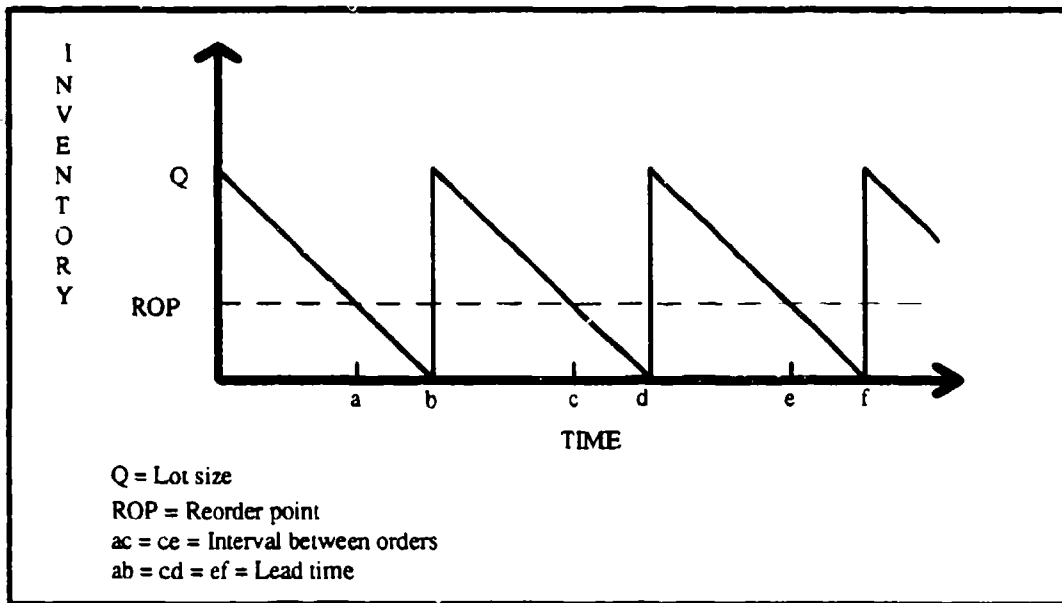
Figure 3. Sawtooth Demand Pattern (Tersine, 1994: 93).

Operating on the premise that ordering and holding costs should be balanced when managing inventory, the EOQ model considers these costs as a means of reducing total variable costs.
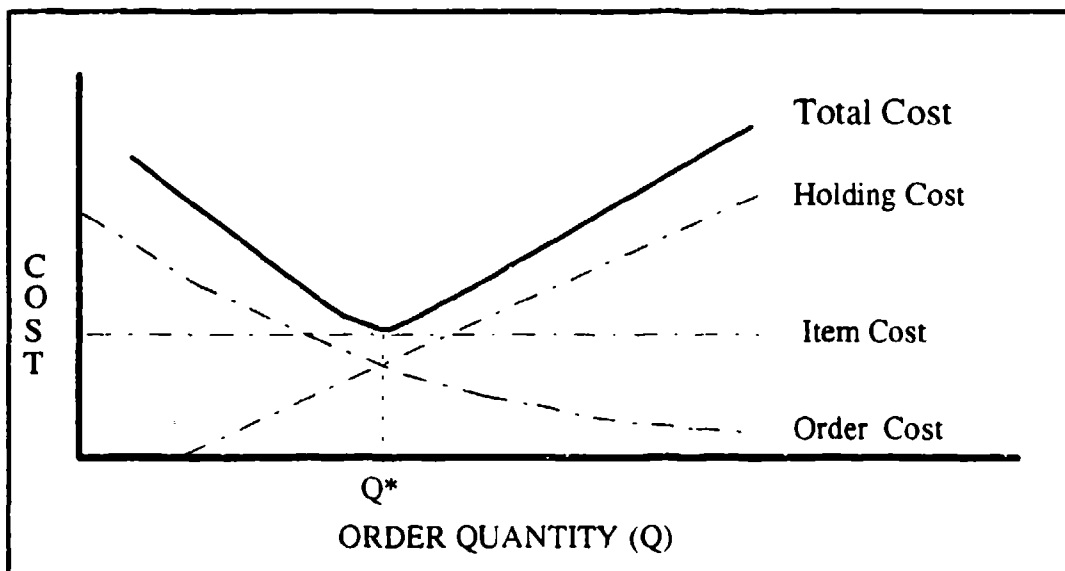


Figure 4. Cost Tradeoff Curve (Evans, 1993: 429 & Tersine, 1994: 94).

Figure 4 demonstrates how these costs are balanced to obtain an optimum point on the total cost curve. Q* represents the point on the curve where the total cost is minimized and the cost to order an asset is identical with the cost to hold.

Wilson's Classic EOQ Formula follows:

$$Q_w = \sqrt{\frac{2RC}{H}}$$

(1)

where,

$\quad\quad Q_w$ = Wilson's Economic Order Quantity

$\quad\quad R$ = Annual Demands

$\quad\quad C$ = Cost to Order

$\quad\quad H$ = Holding Cost

and,

$$H = Pf$$

(2)

$\quad\quad P$ = Price

$\quad\quad f$ = Holding Cost Factor

Certain assumptions about the demand, replenishment, and time elements of the system must be made to use the EOQ model. These assumptions are given again as previously in table 2 of Chapter one.

**Table 2.**

**Assumptions Required by Wilson's Classic Economic Order
Quantity Model**

---

1. The demand rate is known, constant, and continuous.
2. The lead time is known and constant.
3. The entire lot size is added to inventory at the same time.
4. No stockouts are permitted; since demand and lead time are known, stockouts can be avoided.
5. The cost structure is fixed; order/setup costs are the same regardless of lot size, holding cost is a linear function based on average inventory, and unit purchase cost is constant (no quantity discounts).
6. There is sufficient space, capacity, and capital to procure the desired quantity.
7. The item is a single product; it does not interact with any other inventory items (there are no joint orders).

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(Tersine, 1994: 95)

Due to the 1958 review and subsequently DODI 4140.11, all DOD activities began following EOQ principles. When DLA assumed management of the DOD consumables, they were compelled to follow the same guidance as the Services (Air Force Tire Program, 1994: 8).

## Defense Logistics Agency

The Defense Logistics Agency (DLA) is an agency of the Department of Defense. "The National Security Act (NSA) established the foundation for the eventual creation of a single, integrated agency to manage general supplies at the departmental level" (Robinson, 1993: 1). On 1 January 1962, Secretary McNamara handwrote general order number 1, bringing DLA into operational status. Today the Defense

Logistics Agency (DLA) provides logistics support throughout the Department of Defense.

The philosophy of DLA is best summed up in its mission statement. Their primary mission is:

> To function as an integral element of the DOD logistics system and to provide effective and efficient worldwide logistics support to DOD components as well as to Federal agencies, foreign governments, or international organizations as assigned in peace and war. Our vision at DLA is to continually improve the combat readiness of America's fighting forces by providing soldiers, sailors, airman, and marines the best value and services when and where needed (DLA, 1991: 2-1)

To put the magnitude of DLA's operation into better perspective, "the Defense Logistics Agency supplies more items and processes more requisitions than all of the other Services plus GSA combined" (Feeney, 1966: 18). "Designed to save resource dollars and achieve management efficiency, Defense Management Review Decision (DMRD) 926 directed the consolidation of inventory control points throughout DOD" (DLA, undated: 1-2) This transfer of inventory control occurred in several phases. The first phase transferred management of over one million DOD consumable items to DLA (Robinson, 1993: 52).

In 1991, the Air Force obtained more than half of its consumable resources from DLA. These consumables items are used on aircraft, helicopters, communication systems, and so

forth (Robinson, 1993: 1). DLA supplies over 459,000 items for the Air Force alone. Due to the costs associated with inventory, it is important that inventory is managed carefully (Robinson, 1993: 16). In fact, due to the public scrutiny of DOD activities, it is critical the Air Force manage its inventory properly.

DLA's materiel management responsibilities include: item management classification, requirements and supply control, procurement, quality and reliability assurance, industrial mobilization planning, storage, inventory distribution, transportation, maintenance and manufacture, provisioning, technical logistics data and information, value engineering and standardization (Mitchell, 1983: 228).

DLA is organized into departments which perform these inventory management functions. Headquarters DLA is located in Cameron Station, Alexandria, Virginia. From Cameron Station, DLA directs distribution regions, supply centers, depots and the Defense Reutilization and Marketing Service (Military Logistics, 1990: 7-13). The organization of DLA is depicted in Figure 5 below:
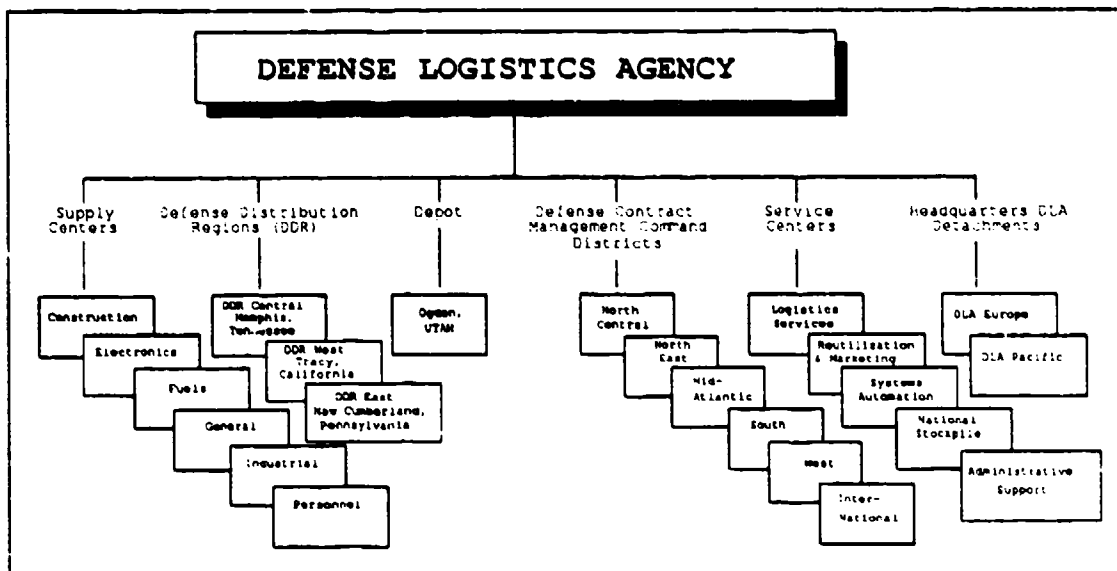
Figure 5. DLA Organization (Robinson, 1993: 7).

Each of six Defense Supply Centers is responsible for a unique class of supplies. They are shown, along with the Distribution regions, in Figure 6:
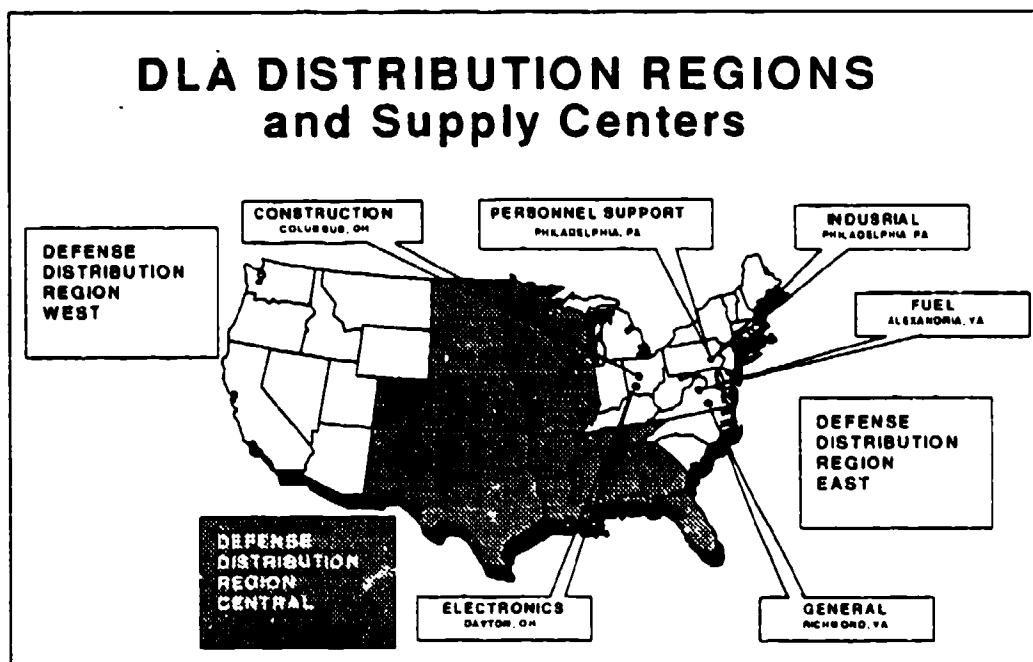


Figure 6. DLA Distribution Regions (Robinson, 1993: 8-10).

When DLA assumed the consumable items for DOD, it also began to develop proper inventory management techniques. Wilson's EOQ was the tool implemented to manage recurring item requirements (Robinson, 1993: 52-64 and Balwally, 1994: Interview).

## DLA Model

As previously mentioned, DLA uses an equation similar to the classic Wilson's EOQ. However, in the classic EOQ formula, R is substituted with DLA's R. (R = 4 x QFD) This R gives DLA's EOQ formula the form (Balwally, 1994: Interview and notes):

$$EOQ_{DLA} = \sqrt{\frac{2(4QFD)C}{hP}}$$

(3)

Where,

$EOQ_{DLA}$ = Economic Order Quantity for DLA

QFD = Quarterly Forecasted Demand

C = Ordering cost

h = Holding rate

p = Standard price per item

The main difference between the classic EOQ and DLA's EOQ is in the calculation of a 'T' value.  T is used by DLA for

extracting ordering and holding cost from the EOQ formula.
It is found by factoring all constant values from the EOQ
formula. The constants being factored out facilitates a
less rigorous computer computation. For DLA, the cost to
hold and order is constant as well as the constants specific
in the equation. The formula is presented as follows
(Balwally, 1994: Interview and notes):

$$T = 2\sqrt{\frac{2C}{h}}$$

(4)

Where,

T = Constant factor representing DLA's method for
extracting constant variables out cf the EOQ
formula.

C = Ordering cost

h = Holding rate

and the Economic Order Quantity is expressed as (Balwally,
1994: Interview and notes):

$$EOQ = T\sqrt{\frac{QFD}{p}} = \frac{T}{2p}\sqrt{AD\$}$$

(5)

Where,

EOQ = Economic order quantity

T = Constant factor representing DLA's method for extracting constant variables out of the EOQ formula.

QFD = Quarterly Forecasted Demand

p = Standard price per item

AD$ = Annual(predicted) demand dollars

and,

$$AD\$ = \left[4(QFD)p\right]$$

(6)

Computing QFD, using DLA's double exponential smoothing formula, requires several steps as represented below (Balwally, 1994: Interview and notes).

First, calculate the single exponential smoothing value,

$$F_t = \alpha A_t + (1-\alpha)F_{t-1}$$

(7)

Where,

$F_t$ = Single forecast smoothing value

$\alpha$ = Smoothing constant

$A_t$ = Actual period demand

$F_{t-1}$ = Single forecast smoothing value, one period in the past

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Second, calculate the double exponential smoothing value,

$$F_t' = \alpha(F_t - F_{t-1}') + F_{t-1}'$$

(8)

Where,

$F_t'$ = Double forecast smoothing value

$\alpha$ = Smoothing constant

$F_t$ = Single forecast smoothing value

$F_{t-1}'$ = Double forecast smoothing value, one period in the past

Finally, QFD can be tabulated using the single and double exponential values such that:

$$2F_t - F_t' = QFD$$

(9)

Where,

QFD = Quarterly forecast demand

$F_t$ = Forecast single smoothing value

$F_t'$ = Forecast double smoothing value

Additionally, DLA adds a variable safety level to the total. This safety level is designed to account for errors in forecasting and for errors that result from the

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stochastic nature of demand during lead time (Balwally, 1994: Interview and notes). Increased responsiveness to a change in demand pattern is a result of this type of safety level computation. This method could have undesirable effects, given the nature of "lumpy" demand.

## Lumpy Demand

Demand can possess different characteristics under various conditions. For example, if an item is required every day in the same quantity, demand for that item would be called stable or static. The inverse of this situation, where demand varies from time period to time period, occurs frequently in material management (Pohlen, 1994: notes). Demand where variation occurs between time periods is sometimes referred to as "lumpy" demand (Tersine, 1994: 178). Tersine, when talking about this type of demand points out

> there are situations where time variations in demand are so pronounced that the constant demand rate assumption (for EOQ models) is seriously violated. Even though demand may be deterministic or known with certainty, its pattern may vary so drastically over time that it cannot appropriately be addressed by techniques that approximate average inventory by a repeating sawtooth pattern. (Tersine, 1994: 178)

It is important, then, that the nature of the demand addressed by a given inventory policy be fully understood. What is the nature of Air Force consumable demand? What effect does this demand have on DLA? Specifically, one must

ask whether demand for consumable items used by the Air Force displays significant variation. Major Douglas Blazer tackled this question in 1985 and concluded the variance to mean ratios for consumable items were *"greater than three"* indicating that the variance was at least three times larger than the mean (Blazer, 1986: 12). It follows that consumable demand should be treated as dynamic and not static based on this finding. The facts Tersine presented above on the applicability of EOQ type models to lumpy demand situations and the conclusion of Major Blazer that Air Force consumable demand is "lumpy," suggest a better model may exist for managing inventory. In other words, because stationary demand is non-continuous and may have a pattern similar to Figure 7, the use of an EOQ requirements policy by DLA may not be the best inventory stockage policy and alternatives should be considered.
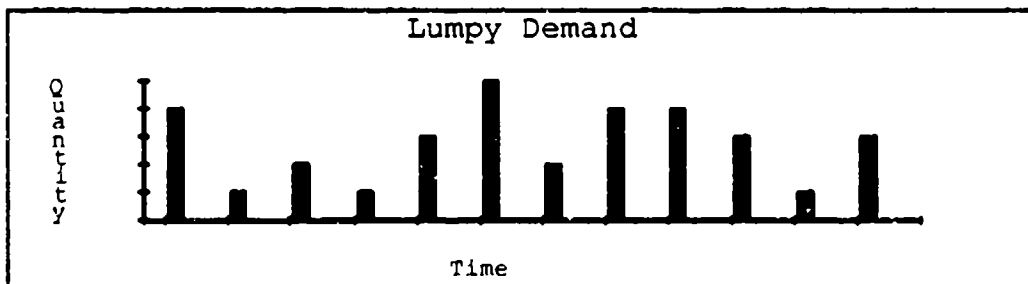


Figure 7.    Lumpy Demand Pattern

## Summary

This chapter's intended purpose is to 1) help understand the current ordering process DLA uses to manage

inventory, 2) explain why inventory is traditionally held 3) explain what is the primary purpose of inventory and 4) why maintain on-hand inventory. Air Force consumable inventory management policy is introduced detailing progress of consumable inventory management for the Air Force. Wilson's classical Economic Order Quantity inventory model and formula was addressed. The EOQ inventory model used at DLA was also presented, outlining the formulas and T value. Finally, an introduction of "lumpy" demand is presented to establish understanding of concerns relating to current inventory management practices of the Defense Logistics Agency.

# III. Methodology

## Introduction

Chapter Three will discuss the methods and techniques used to answer the research questions. This chapter is organized using the basic steps for designing an experiment. First, the design of experiment will be presented. The problem is restated to provide focus for the design steps. Also, data collection and analysis techniques are addressed. A description of the experimental factors and levels follows and the dependent and independent variables are established for the research methodology. Next, simulation is presented as the most appropriate methodology tool for this experimental design. Steps taken to develop the model and the model description are given. Finally, model considerations such as starting conditions, assumptions, and validation and verification are discussed and the statistical methods that will be used to evaluate model output data.

## Design of Experiment

Douglas Montgomery defines experimental design as follows:

> A designed experiment is a test or series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for change in the output response. (Montgomery, 1991: 1)

It is very important to design the experiment in research. The experimental design is the road map that keeps the researcher on track toward satisfying the research objective and addressing the problem presented. Although it is a road map that is developed in the early stages of the research, the experimental design must remain flexible to modification and update. This is because research is an iterative process that requires a researcher to learn and make changes as he or she becomes more involved in the process. Often, an idea of the research objective is identified before a clearly defined path to get there is developed. The most logical path is chosen and when an obstacle is encountered, the researcher either goes around, over, or through it depending on what tools are available. Sometimes the only option may be to chart an entirely new path altogether. This is the nature of experimental design.

Along with the importance of designing the experiment, Montgomery stresses the importance of keeping the statistics that will be used in the research in focus as the research is being developed (Montgomery, 1991: 8). By keeping in mind the analysis that will be necessary throughout the experiment, more meaningful, generalizable conclusions can be drawn from the research. This adds to the validity of the research and makes it harder to dispute the findings after the fact.

Some basic guidelines have been developed for designing experiments. These guidelines provide a step by step approach and can be applied to this research. Table 4 lists these guidelines.

Table 3.

Steps for Experimental Design

---

1. Recognize and state the research problem.
2. Choose independent variable factors and levels for each.
3. Select the appropriate dependent response variable.
4. Choose the experimental design best suited to the research.
5. Perform the experiment.
6. Analyze the data resulting from the experiment.
7. Draw logical conclusions and make recommendations

(Montgomery, 1991: 9-11 and Lorenzen & Anderson, 1993: 3)

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These guidelines were followed in designing the experiment for this analysis and each of the first four will be covered in detail in this chapter. Steps five and six are reserved for discussion in Chapter IV, although the analysis methods will be presented in this chapter. Step seven will be discussed in Chapter V.

Step 1: Problem Recognition and Statement. The problem was presented and outlined in detail in Chapter I but will be briefly restated here to concentrate and focus discussion of each step. Concern exists as to whether the Economic Order Quantity (EOQ) model is appropriate for handling

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stationary but non-continuous demand, also referred to as "lumpy" demand. In a multi-echelon system, the variation of order quantity size is amplified from system level to system level. Eventually, the greatest variation of all levels falls on the last level in the chain (Tersine, 1994: 458). The research hypothesizes that EOQ models do not take necessary measures to account for these extreme variations. Specifically, the problem addressed by the research is whether the EOQ model is an appropriate model for a "lumpy" demand situation based on the inventory levels, total variable costs, and service levels that are generated by this type of demand.

To address this problem, the researchers examined a system that they were familiar with and one that was accessible in terms of data collection. Research was done on the system process by which the Defense Logistics Agency (DLA) stocks and supplies consumable items to Air Force customers. Appendix A outlines the details of the policy used by DLA that was extracted and incorporated into the researched system. This policy description was developed from interviews and discussions with personnel at the Defense Electronics Supply Center (DESC) in Dayton, Ohio (Balwally, 1994: Interview).

Step 2: Factor and Level Determination. Factors for this research were determined based on researcher and advisor experience and knowledge of the EOQ model. Three

factors were determined to be most appropriate for this study. These factors were demand pattern, annual demand, and total lead time. Before discussing each factor in detail, the process of data collection will be discussed.

The data collection referred to here is not the data upon which conclusions and recommendations are drawn. Instead, it refers to the process where data were gathered from DESC to be used to build the experimental model and to calculate levels for each of the three research factors. Personnel from DESC, Mr. Balwally and Mr. Bilikam, provided the researchers with data on 525 stock numbers managed at their location. Based on their experience, items were chosen that displayed a wide range of demand patterns, annual demand values, and lead times. All of the stock numbers provided were managed under the EOQ policy at DLA and the following information was provided on each: the national stock number for the item, the past sixteen quarters of demand history, the calculated quarterly forecasted demand, the administrative and production lead times for each item, and nomenclature. These data were used extensively to calculate levels for each of the factors described below. Appendix B contains a partial list of the data used in this research.

First and foremost, the demand pattern displayed by activities placing demand on DLA was a primary concern. Since the study is concerned with "lumpy" demand, it was

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important to use demand patterns that would present a wide range of realistic "lumpy" demand conditions. For example, if all activities ordered frequently, it is much more likely the situation would closely resemble a constant demand pattern, which the EOQ model assumes. If all activities ordered infrequently, it would be expected that demand would be more "lumpy". Therefore, it was essential to choose levels that would yield various frequency patterns to avoid biasing the experiment.

To specify levels for this factor, it was necessary to define frequent and infrequent orders for the requesting activities. Frequent orders were taken to be an average of one order per month while infrequent orders were taken to be an average of one order every six months. Three varying levels were established for the demand pattern factor using these definitions. The first level has all activities order on a frequent basis. At the second level, half of the activities order frequently and half infrequently . The third level was all activities ordering on an infrequent basis. For model simplicity, the percentage of DLA's annual demand that would be an individual activity's economic order quantity over any particular period was used to define the three levels of the demand pattern factor. Also, the number of requesting activities was limited to four. The steps taken to derive the demand pattern percentages can be found in Appendix C, as well as the calculations for the levels of

the factors yet to be described. Actual percentage values are shown in Table 5.

A second factor important to the researched system is the annual demand placed on DLA. The effect that annual demand has on an EOQ model when that model is subjected to stationary but non-continuous demand is a primary consideration of this research. An EOQ model may react differently to the combination of a "lumpy" demand pattern and low annual demand than it does to the combination of a "lumpy" demand pattern and high annual demand. In order to evaluate these possibilities, a range of annual demands had to be specified. The levels for this factor were set at high, medium, and low based on collected data. Annual demand values used are shown in Table 5 and data analysis to arrive at these values is discussed in Appendix C.

Lead time is an important factor in any supply policy or model and needs to be considered when setting inventory levels. It effects the level of inventory that must be held to maintain a specified customer service level as well as the total variable cost, by causing fluctuations in the amount of time it takes to replenish the organization. Under the scope of "lumpy" demand, a longer lead time may lead to a greater probability of negative effects, such as a higher incidence of stockouts and a lower than expected average on hand inventory. Due to the greater probability of negative effects, this study focuses on lead time as the

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final design factor. As with annual demand, levels for lead time were set as high, medium, and low using the collected data. Appendix C shows the calculations that yielded the levels shown in Table 5 below.

Table 4.

Experiment Factors and Levels

| Factors | Levels | Values | |
|---|---|---|---|
| | | (Activity 1&2) | (Activity 3&4) |
| Demand Pattern (perce :tage of annual demand) | Low | 2.1% | 2.1% |
| | Mixture | .7% | 4.1% |
| | High | 12.5% | 12.5% |
| Annual Demand (units) | Low | 70 | |
| | Medium | 481 | |
| | High | 3750 | |
| Lead Time (months) | Low | 3.26667 | |
| | Medium | 7 | |
| | High | 14.4 | |

Step 3: Response Variable Selection. Research seeks to advance the knowledge available on a particular subject. This study attempts to advance the knowledge on the EOQ model and its use by DLA by showing the effects of an occurring situation on the current model. Appropriate measures must be established that can be used for comparison purposes. In other words, response variables that can be

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measured and used to draw conclusions about the researched system need to be identified. Three such measures were defined by the researchers for this experiment. Those measures are total variable cost, average on hand inventory, and the pre-replenishment inventory position at the distribution center.

Total variable cost is an important consideration when talking about the EOQ model. This model seeks to minimize total variable cost by balancing ordering costs with holding costs. If it could be shown that the actual total variable cost driven by a "lumpy" demand situation is different from that expected for the given annual demand, then it would follow that the stationary but non-continuous demand pattern has an effect on the EOQ model's performance, at least in terms of money spent, i.e., total variable cost. This is the reason that the researchers chose total variable cost as one response variable for evaluation. It should be noted, however, that this variable is not specifically output from the model but can be derived from two model output variables, average on-hand inventory and average orders per year. It is legitimate to calculate this response outside of the model after all simulation runs have been made because the calculations for holding and ordering costs are based only on average values. They do not include measures of variance.

As mentioned above, average on-hand inventory is used to calculate total variable cost. This is not the only reason that this response variable is important to the research. By establishing the amount of average on-hand inventory that "lumpy" demand drives the inventory center to keep on the shelf, the results may suggest approaches for determining the amount of safety stock that should be held to satisfy customer demand at a given customer service level. However, on-hand inventory alone cannot be used to accomplish this. It would be incorrect to state that because average on-hand inventory is always positive, safety stock need not be held for a particular item. In conjunction with the average on-hand inventory, the inventory center's stockage position, just prior to replenishment from the vendor, must also be considered. A combination of the two variables allow conclusions to be presented on what level of safety stock should be held, and at what cost, to provide the desired customer service level.

Through the above response variables, measurements have been established that correspond with measures that are necessary for judging the success of any inventory policy or model. The responsiveness of the model to customer demand is considered along with the cost to provide that service level. If "lumpy" demand causes costs to be driven upwards or customer service downwards under the EOQ model, EOQ may not be the most appropriate model to handle this situation.

Step 4: Experimental Design Choice. This step includes "the consideration of sample size (number of replicates), the selection of a suitable run order for the experimental trials, and determination of whether or not blocking or other randomization restrictions are involved" (Montgomery, 1991: 10). For the purpose of this research, it is necessary not only to discuss the statistical tools used in the experimental design but also the method for obtaining output data. The system under study is very complex and it would be impractical to try and manipulate it for research purposes. Manipulation like that would disrupt daily operations and prove very expensive.

An alternative to system manipulation for the purpose of learning more about a process is simulation. "Computer simulation is the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer" (Pritsker, 1986: 6). The advantages to studying a system in this manner are that the system can be studied without building it if it is a new proposal, disrupting it if it is already in operation, or destroying it if the desired tests will do so (Pritsker, 1986: 6). Van der Walde, in an article entitled "Computer Simulation in Manufacturing", stressed simulation's usefulness in making current operations more efficient and in cases where the system is too complex to evaluate otherwise (Van der Walde, 1991: 80). Simulation was chosen in this research effort as

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the most appropriate tool for obtaining output data due to the nature of the system being researched.

There are basic steps involved in creating a simulation model (Table 6). Previous discussion has addressed several of these steps already but there are several others deserving explanation.

Table 5.

Pritsker's Ten Steps for Successful Simulation

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1. *Problem formulation.* The definition of the problem to be studied including a statement of the problem-solving objective.
2. *Model building.* The abstraction of the system into mathematical-logical relationships in accordance with the problem formulation.
3. *Data acquisition.* The identification, specification, and collection of data.
4. *Model translation.* The preparation of the model for computer processing.
5. *Verification.* The process of establishing that the computer program executes as intended.
6. *Validation.* The process of establishing that a desired accuracy or correspondence exists between the simulation model and the real system.
7. *Strategic and Tactical planning.* The process of establishing the experimental conditions for using the model.
8. *Experimentation.* The execution of the simulation model to obtain output values.
9. *Analysis of results.* The process of analyzing the simulation outputs to draw inferences and make recommendations for problem resolution.
10. *Implementation and documentation.* The process of implementing decisions resulting from the simulation and documenting the model and its use.

(Pritsker, 1986: 10-1)

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Problem formulation and data acquisition steps were covered in the description of steps for designing the experiment. Appendix A provides a detailed description of

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the portions of DLA's requirements system to be studied and modeled in this research. However, further discussion must accompany description of the research simulation model.

Using the Digital Equipment Corporation (DEC) VAX 6420 Mainframe computer, a simulation model was built on Pritsker's SLAM II software(Version 4.1). This model was compiled and linked to author written FORTRAN subroutines using the DEC VAX FORTRAN Compiler (Version 6.1). The purpose of the model was to represent and replicate a situation of "lumpy" demand placed on the inventory model and policies currently used by DLA.

The authors made the assumption that only four activities place demands on DLA. Each of these activities, however, could represent multiple bases or customers. The customers place demands for set quantities on the inventory center, based on the activity demand pattern factor and the annual demand factor for DLA. Demands occurred in a stochastic manner but averaged two per year for the infrequent ordering activities and twelve per year for the frequent ordering activities.

At the model distribution center, demand was received and the on-hand balance was decreased. For the purpose of this study, safety stock was not included in the and customer service levels could be made based on the average on-hand inventory level and the pre-replenishment

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inventory position. This technique also facilitated preventing the effects of "lumpy" demand on the EOQ model from being masked in the variable safety level method used by DLA.

As the on-hand balance declined, the level of available inventory was checked against the system reorder point to see if an order for replenishment at DLA needed to be placed with the vendor. Also, to accommodate possible long lead times, negative inventory balances were checked against their corresponding reorder points to see if multiple replenishments needed to be placed to prevent the inventory level from falling into a bottomless pit. This method of ordering corresponds to the actions you would expect an item manager to take if he or she sees the level of backorders for a particular item continuously rising.

While customer demand is occurring, the simulation processes other internal actions that are consistent with DLA's inventory policies. Based on past demand, a quarterly forecast for upcoming demand is made using a double exponentially smoothed method of forecasting. This forecast is then used by the model to calculate the economic order quantity and the reorder points used to maintain replenishment at the inventory center. Appendix D provides a walk through of the model, how it is designed to work, and specific mathematical relationships that are included as a part of the system.

One assumption made in the model that should be explained concerns the use of a beta distribution for time between creations of activity demands. The beta distribution was chosen because it has finite endpoints. In other words, unlike the normal distribution, the beta has no infinite tails that may return extremely large, unrealistic time between demands. From the researcher's perspective, it seems more realistic to state if an activity orders on average twice per year, every three to nine months an order can be expected. Likewise, if an activity orders an average of twelve times per year, it is reasonable to assume an order will occur every half to one-and-a-half months. A beta distribution allows this to be modeled as described.

Verification and Validation. Verification is the process of determining if a model works as it is intended (Shannon, 1975: 30). Validation, on the other hand, "is the process of bringing to an acceptable level the user's confidence that any inference about a system derived from the simulation is correct" (Shannon, 1975: 29). Both of these tasks must be accomplished if conclusions drawn from the research are to be accepted. For this research, verification was accomplished by analytically and intuitively evaluating the output values that the model returned. It was obvious early in the design process that the model was not responding as expected. Consultation with advisors and a systematic breakdown of each model component

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revealed errors in the FORTRAN programming, the SLAM II network arguments, and the DEC compiler process. Once steps were taken to correct these errors, the model ran as intended.

Validation was accomplished by first interviewing the experts at DESC to determine which policy considerations needed to be considered in the system model. Next, these system specifics were presented to the thesis advisors and discussions ensured that the research model was consistent with DLA's inventory policy, the EOQ model, and the simulation techniques to be used. Finally, verification and validation were brought together under the umbrella of pilot runs. From the pilot runs, a final check of the model and output data showed the model to be both valid and verified.

Strategic and Tactical Planning. Several concerns existed for the starting conditions of the model. First, the demand pattern factor is based on the percentage of DLA's total annual demand that represents the expected order size for the activity. The size of the order is a function of the frequency that the activity orders. For this reason, differing times between creations had to be assigned to activities, depending on whether the activity ordered frequently or infrequently. To accommodate this in the model, three different networks had to be constructed. The only difference between the networks was the time between creations assigned to activities. One network, where all

activities ordered frequently, used the beta distribution with a mean of one month and endpoints of a half and one-and-a-half months. The second network, where two activities ordered frequently and two ordered infrequently, had the frequent activities with the above distribution for time between creations and the other two with a beta distribution with an average of six months and endpoints of three and nine months. Lastly, one network used the beta distribution with mean six for all four activities. Other than the time between creation functions all networks were the same in every way.

Another starting condition concern was the amount of inventory placed at the inventory center when the model begins. If no inventory is on hand, the model will try to reorder immediately. Unfortunately, because no demands have been recorded, there would be no quarterly forecasted demand and therefore the model would order zero from the vendor. One possible method to overcome this condition is to assign an initial economic order quantity for the model and proceed as described above. The problem is that the model would have to go into a negative on-hand balance immediately because there is no stock on hand. To overcome these considerations, the model was started with an on-hand balance equal to the expected economic order quantity for the given factors. Also, the initial order quantity for DLA to place with the vendor was set as the expected economic

order quantity for the given factors. Appendix E shows the SLAM II model control deck initializations for each treatment and Appendix F provides explanation for the calculation of the variables.

The final starting condition problem to be overcome was eliminating the bias that is created by the system not being in steady state as soon as the model begins to run. One method to eliminate the initial bias is to determine the point in model time at which the initial conditions no longer effect model results. Schruben, Singh, and Tierney have proposed a method for determining that time by associating t-statistics with the difference between the response variable and the overall mean of the response variable at each particular simulation time (Kleijnen, 1987: 110-1). A critical t-statistic is then compared to the individual t-statistics to determine when the start up conditions no longer have an effect.

A pilot run of the model was made for 8,000 months and response variables were collected. The method described above was used to determine at what time statistical arrays should be reset to eliminate initialization bias. Appendix G shows graphically the results of these runs and the time increment associated with each treatment's critical t-value. To ensure that initialization bias was gone, the longest time period for any treatment was chosen as the least amount of time that should expire before statistical arrays

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cleared. A safety factor amount of time was then added to this time increment. Final determinations had the model run for 11,000 months and arrays were cleared at 8,000 months.

## Statistical Analysis

As the experimental design was established for this study, the statistical design was the fixed effects, three by three, full factorial model. Several advantages accompany a full factorial design, such as the efficiency as compared to a single factor design and the ability to measure the effects of a variable over several levels (Montgomery, 1991: 201). In a full factorial design, every combination of variables is considered in a single run. The model is called a "three cubed" because there are three factors at three levels each.

Comparisons of the means of the response variables can be made from the above design using analysis of variance (ANOVA). ANOVA returns a test statistic that can be used to determine the effects of the various factors. In order to use the results from the factorial design under the ANOVA technique, two assumptions must be met. First, the distributions returned for each treatment must be approximately normal. Second, the variance for all treatments must be the same. The author's intent was to apply the ANOVA to output data that will be presented in

Chapter IV.  Before this is done, the assumptions will be checked to see if they hold.

## Summary

Chapter III presented the techniques employed in this experiment to answer the research questions.  A step by step description of the process to design the experiment was given, model factors and levels were presented, and the model response variables were justified.  Simulation was chosen as the tool to extract output data to prevent trying to manipulate the actual complex system.  Steps for building the model were given along with accompanying assumptions, validation and verification considerations, and steady state concerns.  Chapter IV will now address the actual experiment and results obtained.

# IV. Data Analysis

## Introduction

This chapter presents the simulation model output data and explains the techniques used to analyze that data. First, differences between the statistical analysis method described in Chapter III and the reasons for those differences are listed. Second, the output data for the average on-hand inventory and the pre-replenishment inventory position are presented in tables. Presenting the data in this fashion allows patterns and the effects of variables to be identified easily. Also, the average annual orders for each treatment is provided. Finally, total variable cost is calculated using the values for pre-replenishment inventory position, average on-hand inventory, and average annual orders. Once the above has been accomplished, recommendations and conclusions can readily be made in Chapter V.

## Differences from the Proposed Statistical Analysis

In Chapter III, the analysis of variance (ANOVA) technique was presented as the statistical method that would be used to evaluate the model output data. Along with this method, two assumptions are required for the ANOVA to be an appropriate statistical tool. Those assumptions are: 1) the distributions returned for each treatment had to be

approximately normally distributed and 2) the variances between the treatments must be the same.

Thirty runs were made for the pilot data allowing the Central Limit Theorem to be invoked. This theorem states that bec use the values being tracked are averages of averages and the sample size of 30 is sufficiently large, the variable distributions will be approximately normal (McClave, 1991: 289). Therefore, the assumption for normality is met

Next, the assumption of equal variances must be considered. This assumption does not hold, as is evident by Table 6 on the next page. From a visual inspection, one can see that the variances are not statistically the same between treatments. The variances of 165,661.97¹ nd 0.0043, or 1021.0926 and 0.0052 are clearly unequal. The assumption of equal variances that accompanies an ANOVA analysis is violated. An ANOVA search for effects could, therefore, not be done. The researchers had to turn to the non-parametric statistical methods for analy.

It was also unrealistic to talk about computing a sample size. Obviously, the standard deviation that would yield the greatest number of runs will use the largest standard deviation, which is the square root of 165,661.971. The sample size calculation would drive a tremendous number of runs using this standard deviation, a realistic width, and a realistic confidence level. An unrealistic number of runs would be required as a result of these calculations.

Table 6.

Treatment Mean and Variances for Average On Hand Inventory
and Pre-Replenishment Inventory Position (over 30 runs)

| Treatment | Average On Hand Inventory | | Pre-Replenishment Inventory Position | |
|---|---|---|---|---|
| | Mean | Variance | Mean | Variance |
| 1 | 6.9868 | 0.0043 | -1.7233 | 0.0052 |
| 2 | 6.7349 | 0.0074 | -2.0016 | 0.0108 |
| 3 | 29.2654 | 0.0426 | -0.0790 | 0.1386 |
| 4 | -0.6620 | 0.0258 | -9.3220 | 0.0285 |
| 5 | -1.3800 | 0.0330 | -10.0751 | 0.0303 |
| 6 | 28.6969 | 0.1081 | -1.3152 | 0.1128 |
| 7 | -33.9823 | 0.4307 | -42.6172 | 0.2993 |
| 8 | -36.9662 | 0.3673 | -45.4957 | 0.3356 |
| 9 | 18.2514 | 0.2264 | -11.5523 | 0.3035 |
| 10 | 50.8089 | 0.1591 | -9.7717 | 0.1458 |
| 11 | 49.2188 | 0.3004 | -11.9661 | 0.5104 |
| 12 | 202.7563 | 5.0392 | -0.2536 | 9.6561 |
| 13 | 0.6149 | 0.7647 | -59.9499 | 0.8863 |
| 14 | -5.8391 | 1.8257 | -66.7873 | 1.6933 |
| 15 | 198.3198 | 5.1306 | -9.3821 | 13.1732 |
| 16 | -228.0464 | 7.8376 | -288.5412 | 5.1404 |
| 17 | -245.0535 | 22.4189 | -306.0829 | 20.3970 |
| 18 | 124.5715 | 16.8034 | -81.1137 | 24.6869 |
| 19 | 399.6766 | 5.0081 | -74.6318 | 5.2279 |
| 20 | 385.3750 | 22.7374 | -93.5506 | 32.8191 |
| 21 | 0.4786 | 0.0895 | 1.7304 | 421.9862 |
| 22 | 6.8308 | 54.1965 | -466.8596 | 47.5829 |
| 23 | -43.6452 | 118.7472 | -520.6367 | 111.1160 |
| 24 | 0.5405 | 0.0651 | -74.9416 | 247.6724 |
| 25 | 0.5462 | 0.0985 | -2242.1010 | 246.6111 |
| 26 | 0.4682 | 0.0944 | -2379.1780 | 1021.0926 |
| 27 | 737.4325 | 165661.971 | -639.3018 | 837.4433 |

(The numbers given for 'Treatment' correspond to those listed in the
tables in Appendix E.)


Turning to non-parametric statistical tests, there is
an assumption that must be met under this type of testing.
Each individual simulation run must be independent of any
other run. When this research model was set up, common
random number seeds were assigned between treatments as a
variance reduction technique. In other words, by having

each model run using the same random numbers for treatments, variance could be reduced between the treatment data to only that caused by the system being modeled. Unfortunately, using common random numbers causes the model to violate the assumption of independence necessary for non-parametric testing.

No statistical tests could be used to establish "statistical" significance in this study due to the assumption violations for both parametric and non-parametric techniques. Instead, conclusions had to be drawn based on practical evaluation of the output data. This does not make the study any less valid. It will be shown that, although there is no way to statistically show significance from the effects of lumpy demand, practically it is very hard to refute the effects of lumpy demand. Practical observations serve to make the research more understandable to those that really need to understand the implications of the conclusions and, therefore, may prove more successful in advancing the body of knowledge in this area.

## Output Data Analysis

Data were gathered from the simulation model on average on-hand inventory, pre-replenishment inventory position, and average annual orders. These variables facilitate discussion on total variable cost and the service level generated by an ECQ system faced with lumpy demand.

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Average On-Hand Inventory. Average on-hand inventory gives an indication of how much stock can be expected on the shelf at any given time. This variable is a key component in the total variable cost formula for calculating the cost of holding. Table 7 shows the model output for this variable and Appendix H displays the data graphically.

Table 7.

Average On Hand Inventory for All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | 737.4325 | 0.4682 | 0.5462 |
| | Medium | 0.5405 | -43.6452 | 6.8308 |
| | Low | 0.4786 | 385.3750 | 399.6766 |
| Medium | High | 124.5715 | -245.0530 | -228.0460 |
| | Medium | 198.3198 | -5.8391 | 0.6149 |
| | Low | 202.7563 | 49.2188 | 50.8089 |
| Low | High | 18.2514 | -36.8662 | -33.9823 |
| | Medium | 28.6969 | -1.3799 | -0.6620 |
| | Low | 29.2654 | 6.734917 | 6.9868 |

There is a recognizable effect of lead time and demand pattern on average on-hand inventory when annual demand is at the medium and low levels. Average on-hand inventory is shifted by an order of magnitude between the medium annual demand and low annual demand level, but the trend over the lead time levels stays the same. This indicates, for medium and low annual demand, higher lead times result in less stock on the shelf. Also, when a frequent demand component is included in the demand pattern, as is the case for mixed

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and low demand patterns, less stock is available than when
the infrequent or high demand pattern is observed.

When annual demand is high, the above observations do
not hold.  This could be attributed to the large variances
that are associated with these treatments.  Because the
demand placed on the inventory center is in the form of
large, infrequent spikes, the on-hand inventory exhibits
extremely erratic behavior.  In other words, the drastic,
infrequent changes in inventory level cause the average
inventory level to react differently than observed for
medium and low annual demand.

Pre-Replenishment Inventory.  The pre-replenishment
inventory was the amount of stock on hand just prior to the
inventory center receiving an order from the vendor.  Output
data for this variable is shown in Table 8 and Appendix H.

Table 8.

Average Pre-Replenishment Inventory for All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | -639.3018 | -2379.1780 | -2242.1010 |
| | Medium | -74.9416 | -520.6367 | -466.8596 |
| | Low | 1.7304 | -93.5506 | -74.6318 |
| Medium | High | -81.1137 | -306.0829 | -288.5412 |
| | Medium | -9.3821 | -66.7873 | -59.9499 |
| | Low | -0.2536 | -11.9661 | -9.7717 |
| Low | High | -11.5523 | -45.4957 | -42.6172 |
| | Medium | -1.3152 | -10.0751 | -9.3221 |
| | Low | -0.0790 | -2.0016 | -1.7233 |

The graphs in Appendix H show an obvious connection between all three levels of the annual demand factor, demand pattern factor, and lead time factor. First, the trend pattern across the lead time levels is the same for each demand pattern as the annual demand is varied. The order of magnitude is different for different levels of annual demand and demand pattern but can be attributed to the change in the annual demand placed on the inventory center. It can be seen that demand pattern causes the amount of stock on hand at replenishment to be less for demand patterns that incorporate an element of frequent demand, namely the mixed and low demand patterns. All pre-replenishment inventory positions are negative, however, except when the lead time is low. Whenever the lead time is low, pre-replenishment levels are close to the desired level of zero on average.

Average Annual Orders. Average annual orders defines the average number of times the inventory center has to order in a year to satisfy customer demand. Tracking this variable is necessary to be able to calculate total variable cost. Interestingly, the number of orders placed during a year varied only with the demand pattern that was defined. If a high demand pattern, with characteristics of infrequent, large quantity orders, was the pattern, the order values were low and ranged from approximately 1.16 to 1.19. For a demand pattern with a frequent component, like mixed and low, the annual orders ranged from approximately

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3.99 to 4.11 orders per year. The data is shown in Table 9 below.

Table 9.

Average Annual Orders for All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | 1.1769 | 3.9968 | 4.0020 |
| | Medium | 1.1795 | 4.0013 | 4.0005 |
| | Low | 1.1649 | 3.9998 | 3.9997 |
| Medium | High | 1.1829 | 4.0137 | 4.0156 |
| | Medium | 1.1857 | 4.0131 | 4.0155 |
| | Low | 1.1708 | 4.0131 | 4.0145 |
| Low | High | 1.1900 | 4.1163 | 4.1137 |
| | Medium | 1.1935 | 4.1140 | 4.1140 |
| | Low | 1.1791 | 4.1125 | 4.1119 |

As expected, the high demand pattern, with its infrequent demand, causes fewer orders to be placed by the inventory center throughout the year, on average.

Total Variable Cost. The final variable to address is total variable cost. This represents the cost at the inventory center to hold and order stock throughout the year. From the above variables, total variable cost can be calculated for each treatment. However, there are some considerations that must be addressed first.

Total variable cost consists of a holding cost component and an ordering cost component. Ordering cost is simply the cost to order multiplied by the average annual number of orders. This variable requires no further explanation. Holding cost is the average on-hand inventory

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multiplied by the holding cost set by the organization and does require further discussion.

From our data, some treatments could show low total variable costs because the annual on-hand inventory was negative. A negative average on-hand inventory indicates that generally there was no stock on the shelf at the inventory center and therefore, no cost of holding inventory. In this case, the total variable cost does not actually reflect the true cost of the system. A total variable cost calculated on the average on-hand inventory alone fails to reflect the cost associated with customer backorders as shown by the negative on-hand inventory. To account for this cost the negative pre-replenisment inventory level was evaluated. If the average pre-replenishment inventory position is negative, the inventory center is always backordering to satisfy customer demand. This indicates that the expected 50% customer service level associated with the classic EOQ model is not being maintained.

To properly account for this discrepancy in the total variable cost calculations, the researchers took the average pre-replenishment inventory position to be the amount of stock that the inventory center would have to carry, in addition to the average on-hand inventory that is already being carried, to reach its 50% customer service level. In this manner, the total variable cost measurement more accurately reflects the success of the inventory model.

Both the efficiency and the effectiveness of the model are reflected in cost measurement. The results of these calculations are shown in Table 10 and, graphically, in Appendix H.

Table 10.

Total Variable Cost Calculated for All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | 208.99 | 3510.29 | 6111.48 |
| | Medium | 117.62 | 1065.75 | 1591.31 |
| | Low | 110.96 | 1010.75 | 1592.81 |
| Medium | High | 226.51 | 3519.42 | 6131.95 |
| | Medium | 227.89 | 1066.50 | 1588.82 |
| | Low | 223.87 | 1009.08 | 1589.42 |
| Low | High | 226.66 | 3596.38 | 6226.99 |
| | Medium | 227.78 | 1101.36 | 1668.14 |
| | Low | 223.87 | 1006.94 | 1584.15 |

Total variable cost is greatest for the treatments that have high lead time; however, it is greater than the expected cost (Appendix F) for *all* but the high demand pattern items. In fact, it is much higher than expected for the mixed and low demand patterns. This would indicate that both lead time and lumpy demand have a significant effect on total variable cost when activities order frequently from the inventory center. However, the medium and low lead times do not seem to be significantly different. The close proximity of the cost values for these two levels indicates that as lead time is decreased under lumpy demand, at some point it becomes unimportant to worry about reducing it

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further.  The results suggest there is an optimal point at which lead time should be set for lumpy demand.

Another important observation concerns the way that the high demand pattern is reflected better than the mixed demand pattern which is in turn better than the low demand pattern.  Part of the model development required different unit costs to be assigned for treatments based on the demand pattern and annual demand.  The discussion on how this was done is in Appendix C and the actual values are in Appendix F.  At any rate, unit price for the items does have an impact on the total variable cost for each treatment.  If the ratio of total variable cost to unit cost is calculated, a better indication of the relative performance of lumpy demand is provided.  Table 11 shows these values.

Table 11.

Total Variable Cost to Unit Cost Ratio All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | 474.98 | 427.04 | 382.69 |
| | Medium | 267.32 | 129.65 | 99.643 |
| | Low | 252.18 | 122.96 | 99.737 |
| Medium | High | 65.464 | 54.939 | 49.237 |
| | Medium | 65.864 | 16.648 | 12.757 |
| | Low | 64.702 | 15.752 | 12.762 |
| Low | High | 9.5356 | 8.1697 | 7.2765 |
| | Medium | 9.5828 | 2.5019 | 1.9493 |
| | Low | 9.4183 | 2.2874 | 1.8511 |

The values in Table 11 show the proportion of total variable cost to unit cost. Perhaps an easier way to think of this is the percentages represent the number of additional units of the item that could be purchased for the same amount of money as the total variable cost. From this analysis, the high demand pattern yields the lowest total variable costs but that cost represents a significant amount of money in relation to the overall price of the item.

### Summary

Simulation output data was presented in this chapter along with a discussion and analysis of the data. Justification was provided for not using statistical tests, and the practical analysis method was justified. Means and variances were provided for average annual on-hand inventory and pre-replenishment inventory position. Tables were then used to analyze the effects of the various factors on the response variables. An analysis of these effects was given for each response variable and this analysis leads directly to Chapter V, where conclusions from the research, implications for DLA, and recommendations for future research will be presented.

# V. Conclusions, Implications and Recommendations

## Introduction

Chapter IV provided data on which conclusions can now be based. This chapter will incorporate the analysis of data from Chapter IV into conclusions on how the Economic Order Quantity model performs under lumpy demand conditions with varying annual demand and lead time. From the conclusions, implications of lumpy demand on the EOQ model will be translated into management implications that DLA should consider, given their multi-echelon EOQ system. Along with the conclusions and implications, several recommendations will follow for future research.

## Conclusions

Each of the research questions from Chapter I will be restated and addressed, based on the data analysis from Chapter IV. The questions are:

**1. What impact does violation of the demand rate and lead time assumptions have on the EOQ model?**

In essence, this asks, "Does lumpy demand impact the EOQ model?" Based on the data from Chapter IV, the answer must be yes. It has been shown lumpy demand causes the average annual on-hand inventory to fluctuate widely between time periods (Appendix G). The use of an EOQ model implies the average annual on-hand inventory should be fairly stable

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from year to year when the basic assumptions are maintained. This is not the case under lumpy demand.

Under the EOQ model the researchers expected an average of zero units on hand at the inventory center just prior to replenishment. With only one exception, *all* pre-replenishment levels were negative. This result could indicate two things. First, lumpy demand will drive the EOQ model to require more safety stock to satisfy demand. In other words, to attain the 50% customer service level expected under the classic EOQ, the inventory center must buy additional safety stock. Second, under lumpy demand the assumption of a normal distribution for demand during lead time appears invalid. If the normality assumption was true, one would expect the mean value for pre-replenishment to be zero. For lumpy demand this appears not to be the case. Combining the findings of negative pre-replenishment levels and the non-normality of demand, it can be concluded that attaining a desired service level under lumpy demand will require more safety stock than anticipated. This in turn requires a larger initial capital outlay and larger annual variable costs.

In developing this model, the possibility that multiple requisitions might need to be placed was considered. A method for expediting was included in the model as a FORTRAN subroutine. Without this subroutine, the model could be put into a situation where a received replenishment did not

raise the inventory level above the reorder point. If that situation occurred the system would never reorder. Therefore, the model would be unfairly biased in its output. Even though the subroutine is included in the model, the **average annual orders turned out to be extremely consistent** between runs. This indicates that even though a large amount of variability in demand occurs, on average the EOQ model still uses a set number of orders. Variability of demand is not considered by the EOQ model.

## 2. How does the EOQ model effect total variable cost at the inventory center under lumpy demand conditions?

The results contained in Chapter IV demonstrate that total variable cost under lumpy demand conditions responds contrary to intuition. According to the total variable cost calculations, medium lead time results in a total variable cost that does not differ from that caused by low lead times. Also, high lead times always cause a greater total variable cost than expected. Low lead time causes more inventory to be held than expected and high lead time causes high backorder occurrences. Contrary to current teachings, the indication is that a lower lead time is not necessarily better. Instead, it may be prudent to seek an optimal lead time under lumpy conditions.

Demand pattern affects the total variable cost as well. The cost generated by inventory center ordering increases as the number of activities that order frequently increases.

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Th..s effect is partially explained in the way the model was established. In Appendix C, it is shown how the demand patterns were derived for each level. These demand patterns were used to calculate economic order quantities for each level of annual demand. They were also used to derive the item cost that is implied by the combination of the given annual dem- d with the given demand pattern. To account for the differing item costs a table of ratios of total variable cost to unit price was constructed. This table shows that the proportion of total variable cost to unit price decreases as the annual demand decreases. Total variable cost was actually worse relative to unit price for the items that displayed the overall lowest total variable cost. All of the conclusions drawn on the basis of total variable cost must be evaluated in conjunction with the conclusions for annual on-hand inventory and pre-replenishment inventory.

### 3. How does the EOQ model effect inventory levels at the inventory center under lumpy demand conditions?

Annual on-hand inventory changes by an order of magnitude for the mixed and low demand patterns. Over tnese patterns, higher lead times result in less inventory on the shelf. Interestingly, this pattern is reversed for the high demand pattern situation. Along with the on-hand inventory, the amount of inventory on the shelf immediately prior to replenishment must be evaluated.

Pre-replenishment inventory is negative for all lumpy demand patterns except one. It can be concluded that lumpy demand causes an organization to stock more inventory than expected to attain the expected service level. Also, the demand patterns that include frequent ordering activities are in a poorer inventory position. Their pre-replenishment inventory positions are deeper below the expected inventory position of zero than the high demand pattern positions.

## Implications

The conclusions have several implications for DLA and other multi-echelon inventory systems. First, since DLA has multiple activities that order the same item frequent: nd infrequently, the mixed demand pattern is probably the most likely pattern experienced. By definition, multiple activities using differing methods for establishing the size of orders create a lumpy demand situation at DLA. In light of the conclusions above, one would expect items with high lead times to cause DLA to have more safety stock on the shelf than would be required if the EOQ assumptions were met. This extra safety stock drives up cost, which is an unacceptable condition given the current budget situation. On the other hand, items with low lead times result in a total variable cost that is very nearly the same as with medium lead times. There may be a point of marginal diminishing returns for savings associated with lead time

reduction. If this is the case, DLA should attempt to locate the optimal lead time.

Given the inability of the EOQ model to handle demand variability, a new inventory lot-sizing technique needs to be explored. The new technique should consider the lead time, annual demand, and demand pattern. One possibility for a new lot-sizing technique is Distribution Resource Planning.

A third implication for DLA management concerns the forecasting techniques used in calculating the EOQ quantities. Lumpy demand drives large variances in the annual on-hand inventory and by its very nature creates demand spikes on the inventory center. Attempting to forecast under these conditions could present a multitude of problems, not the least of which is an inaccurate forecast and an incorrect order quantity.

## Recommendations for Future Research

Based on the experience of the researchers, it is recommended a more narrow focus on factors and levels be taken. One of either the high, medium or low levels for annual demand used in this study should be the focus for a future research effort. Also, the number of levels taken from the chosen factor should be limited. This study provides a basis for lumpy demand research. The research

can provide a foundation for more research evaluating the effect of lumpy demand on supply support.

It is also recommended, if the exact same study is performed again, common random number streams not be used in the 30 sample model runs. This will facilitate the use of non-parametric statistical techniques. However, if the scope of research is narrowed sufficiently through implementation of the recommendations above, the variances produced by the runs should be much closer to each other. Closer variances would allow the use of parametric techniques like the ANOVA.

Additionally, if a factorial design is followed, it is recommended that the number of factors be limited to two with three levels each or three with two levels each. The three cubed full factorial design used in this research proved more complex than was desirable and somewhat complicated the statistical and practical analysis.

In addition to the considerations above for modifying the current study, several topics with slightly different angles were discovered or uncovered. The researchers suggest that:

1. Other techniques could be explored to uncover a method accurately coping with lumpy demand.

2. Additional EOQ data could be tracked from the models developed in this thesis on EOQ quantities. This will facilitate the calculations of total variable cost.

Another important aspect is it allows comparisons between DLA's forecasted EOQ and expected EOQ values.

3. A representative sample from additional DLA supply centers could be used in conjunction with a more narrow scope. The methodology in this research could be used.

4. Appendix I displays a situation where the total variable cost prescribed by differing lead times is contrary to the usual connotations of reducing lead time. The conclusion of Appendix I suggests there may exist an optimal lead time under lumpy demand and that lead time is other than the minimum lead time that may be achieved. This timing aspect warrants further study.

5. Using the results from this study, modify the model to lock in not only the holding and ordering costs but also the cost of the item. This will allow a baseline for comparison with the new model.

6. One of the conclusions of this study pointed to the possibility that the distribution of demand during lead time under lumpy demand conditions may not be normally distributed. A study focusing on determining exactly which distribution demand does follow during lead time could be beneficial to organizations using a multi-echelon EOQ system.

## Summary

The results of this study advanced the knowledge in the area of the EOQ approach to lot-sizing. Further, this study enabled conclusions to be drawn that have important implications for DLA. Also, many questions were raised during this research that should be pursued. The questions raised were presented in the discussion on future research. This is not the end but another beginning.

# Appendix A: DLA Inventory Policy Incorporated
## Into the Research System

1. Bases levy demand on DLA. This demand is for a *batch quantity* and will be used to replace depleted inventory levels at the base. The batch quantity concept is important for establishing "lumpy" demand conditions. It is also justified idea because Air Force bases are supposed to manage consumables at their level using an economic order quantity model.

2. a) DLA has enough stock on-hand to satisfy the demand and ships the items to the requesting base immediately.

b) DLA has stock on-hand to satisfy part of the demand but not all. A partial shipment is processed for the available quantity and the remainder of the needed items are placed on backorder.

c) DLA has no stock on-hand and a backorder is established for the entire quantity requested by the base.

3. At the time each demand is received, the reorder point established by DLA to know when to order replenishment stock from the vendor, is checked to see if the on-hand balance has been decreased beyond that point. If the reorder point

has been surpassed, an order is placed with the vendor for DLA's calculated economic order quantity.

4. Based on a particular items characteristics, the quarterly forecasted demand (QFD), economic order quantity, and reorder point are calculated, using the formulas given in Chapter II, either monthly or quarterly. If the economic order quantity is less than the quarterly forecasted demand, the quantity to be ordered from the vendor is set at the quarterly forecasted demand. Likewise, if the economic order quantity is greater than four times the QFD (or one year's forecasted demand) then the order quantity is set as one year's forecasted demand.

5. Once the need for replenishment has been established at DLA, the requirement is sent to the procurement function and administrative lead time elapses as a contract is processed. The vendor receives the order and production lead time elapses as items are produced and shipped to DLA.

6. Replenishment stock is received by DLA, backorders are filled, and remaining material is placed on the shelf to satisfy future requirements.

Note: The actual DLA system is much more complex than is represented here. Only those policy decisions that effect or are effected by "lumpy" demand were included in this study.

# Appendix B: A Sample of the Collected Data from DESC and Histograms for the Lead Time and Average Annual Demand

A sample of the collected data follows on the next two pages. This sample was taken from the 525 stock numbers provided by personnel at DESC. Below is a glossary of the headings that describe the variables in the tables.

| Glossary of Variable Headings | |
|---|---|
| **Heading** | **Definition** |
| Stock # | The National Stock Number assigned to the item. |
| Quarters(1-16) | Demand history for the item. Quarter 16 represents the most recent quarter. |
| ALT | Administrative Lead Time - The length of time it takes DLA to process a requisition contract to the vendor. |
| PLT | Production Lead Time - The length of time it takes the vendor to supply the needed item. |
| QFD | Quarterly Forecasted Demand - A double exponential forecast of the quarterly demand that will be placed on DLA. |
| S1 | The single smoothed value used in the forecast technique. |
| S2 | The double smoothed value used in the forecast technique. $(2*S1-S2=QFD)$ |
| VSL | Variable Safety Level - The computed amount of safety level to be maintained for an item. |
| Nomenclature | The noun description of the item. |

Also, histograms of the Total Lead Time and Average Annual Demand are included in this appendix. These histograms are the basis for the assignment of levels to the Lead Time and Annual Demand Factors in this experiment. See Appendix C for further discussion on this.

## A Sample of Collected Data

**Quarters**

| Stock # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1260010735896 | 16 | 7 | 42 | 16 | 6 | 45 | 15 | 27 |
| 1440005727648 | 542 | 577 | 965 | 928 | 742 | 251 | 429 | 724 |
| 5805001408643 | 480 | 316 | 215 | 249 | 460 | 200 | 328 | 298 |
| 5805010773349 | 54 | 261 | 15 | 48 | 11 | 35 | 73 | 74 |
| 5805011775421 | 4927 | 10325 | 7680 | 6377 | 4299 | 8745 | 6414 | 5225 |
| 5815006517030 | 691 | 289 | 352 | 475 | 52 | 13 | 23 | 27 |
| 5815009781363 | 1592 | 1855 | 2031 | 1474 | 1083 | 2464 | 1137 | 878 |
| 5895004375925 | 4 | 5 | 5 | 3 | 0 | 3 | 3 | 2 |
| 5895011706715 | 4 | 1 | 5 | 3 | 2 | 0 | 5 | 5 |
| 5905000037717 | 83 | 104 | 47 | 62 | 4 | 379 | 466 | 21 |
| 5905000069064 | 1 | 5 | 2 | 0 | 0 | 1 | ·0 | 2 |
| 5905000514631 | 27 | 14 | 6 | 42 | 8 | 25 | 7 | 7 |
| 5905001048353 | 352 | 510 | 215 | 275 | 610 | 375 | 145 | 544 |
| 5905001114840 | 56 | 170 | 280 | 300 | 60 | 163 | 310 | 65 |
| 5905001193503 | 1838 | 3105 | 1208 | 2234 | 3055 | 3305 | 1937 | 2060 |
| 5905001383431 | 2 | 2 | 3 | 6 | 1 | 0 | 101 | 2 |
| 5905001405657 | 76 | 114 | 164 | 78 | 72 | 638 | 536 | 126 |
| 5905001424523 | 112 | 139 | 133 | 116 | 109 | 362 | 61 | 187 |
| 5905001514666 | 10 | 60 | 0 | 0 | 0 | 0 | 0 | 3 |
| 5905001636958 | 103 | 5 | 5 | 15 | 51 | 27 | 1 | 49 |
| 5905001734835 | 70 | 40 | 130 | 30 | 49 | 67 | 470 | 340 |
| 5905001872066 | 152 | 0 | 0 | 50 | 50 | 0 | 0 | 0 |
| 5905002084358 | 30 | 7 | 21 | 66 | 10 | 50 | 7 | 12 |
| 5905002323112 | 172 | 380 | 170 | 110 | 11 | 0 | 10 | 0 |
| 5905002368118 | 1 | 1 | 6 | 0 | 31 | 81 | 16 | 17 |
| 5905002448512 | 40 | 96 | 377 | 10 | 245 | 447 | 138 | 786 |
| 5905002541051 | 19 | 305 | 249 | 209 | 66 | 505 | 12 | 280 |
| 5905002602608 | 39 | 29 | 3 | 9 | 11 | 14 | 29 | 15 |

# Sample Collected Data (Continued)

## Quarters

| Stock # | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| 1260010735896 | 14 | 13 | 0 | 15 | 38 | 26 | 25 | 1 |
| 1440005727648 | 340 | 215 | 283 | 145 | 120 | 134 | 518 | 216 |
| 5805001408643 | 210 | 225 | 183 | 286 | 140 | 274 | 137 | 87 |
| 5805010773349 | 37 | 71 | 1 | 11 | 136 | 15 | 28 | 30 |
| 5805011775421 | 4690 | 10813 | 3450 | 4209 | 6144 | 19916 | 6679 | 8332 |
| 5815006517030 | 1 | 25 | 55 | 20 | 15 | 5 | 13 | 5 |
| 5815009781363 | 1801 | 1460 | 616 | 808 | 995 | 1550 | 476 | 265 |
| 5895004375925 | 2 | 0 | 21 | 77 | 7 | 20 | 13 | 98 |
| 5895011706715 | 3 | 5 | 3 | 3 | 2 | 17 | 18 | 2 |
| 5905000037717 | 17 | 32 | 1 | 7 | 147 | 538 | 266 | 30 |
| 5905000069064 | 0 | 0 | 0 | 0 | · 31 | 1 | 0 | 1 |
| 5905000514631 | 6 | 2 | 12 | 2 | 3 | 5 | 4 | 0 |
| 5905001048353 | 25 | 547 | 493 | 95 | 276 | 390 | 143 | 555 |
| 5905001114840 | 125 | 39 | 53 | 70 | 150 | 230 | 230 | 60 |
| 5905001193503 | 1464 | 775 | 1321 | 1110 | 1330 | 1170 | 930 | 1605 |
| 5905001383431 | 0 | 20 | 2 | 0 | 4 | 20 | 21 | 0 |
| 5905001405657 | 60 | 15 | 145 | 54 | 30 | 123 | 0 | 199 |
| 5905001424523 | 155 | 21 | 13 | 27 | 15 | 20 | 2 | 17 |
| 5905001514666 | 0 | 0 | 0 | 5 | 0 | 13 | 10 | 0 |
| 5905001636958 | 6 | 10 | 3 | 1 | 90 | 25 | 250 | 222 |
| 5905001734835 | 140 | 150 | 30 | 40 | 10 | 20 | 10 | 10 |
| 5905001872066 | 0 | 0 | 0 | 2 | 0 | 1 | 12 | 5 |
| 5905002084358 | 23 | 27 | 24 | 22 | 6 | 25 | 6 | 0 |
| 5905002323112 | 10 | 0 | 0 | 10 | 110 | 0 | 0 | 0 |
| 5905002368118 | 52 | 15 | 34 | 10 | 1 | 0 | 55 | 1 |
| 5905002448512 | 729 | 429 | 20 | 314 | 97 | 106 | 42 | 89 |
| 5905002541051 | 2 | 1 | 1 | 3 | 13 | 191 | 247 | 40 |
| 5905002602608 | 26 | 15 | 6 | 3 | 34 | 6 | 13 | 3 |

## Sample Collected Data (Continued)

| ALT | PLT | QFD | S1 | S2 | VSL | Nomenclature |
|---|---|---|---|---|---|---|
| 83 | 125 | 19 | 245 | 303 | 43 | COVER FIRE CONTROL |
| 98 | 362 | 257 | 2415 | 2264 | 1139 | FLAG ASSEMBLY |
| 85 | 325 | 207 | 681 | 675 | 787 | TELEPHONE TERMINAL |
| 150 | 227 | 29 | 386 | 484 | 0 | TELEPHONE CIRCUIT T |
| 78 | 332 | 4305 | 15839 | 17325 | 9596 | TELEPHONE SET |
| 72 | 129 | 13 | 169 | 207 | 29 | HOLDER NUMBER TAPE |
| 150 | 260 | 513 | 7566 | 9999 | 2311 | PLATEN PRINTER |
| 88 | 44 | 33 | 330 | 330 | 0 | PANEL INDICATOR |
| 139 | 207 | 8 | 97 | 115 | 0 | KEYER |
| 48 | 166 | 210 | 2006 | 1912 | 494 | RESISTOR FIXED FILM |
| 63 | 119 | 2 | 39 | 63 | 4 | RESISTOR FIXED WIRE |
| 30 | 184 | 1 | 46 | 80 | 2 | RESISTOR FIXED COMP |
| 33 | 109 | 336 | 3386 | 3408 | 524 | RESISTOR FIXED COMP |
| 39 | 118 | 190 | 1900 | 1900 | 328 | RESISTOR FIXED COMP |
| 58 | 68 | 1179 | 13891 | 15989 | 1111 | RESISTOR FIXED COMP |
| 55 | 145 | 9 | 100 | 113 | 20 | RESISTOR FIXED FILM |
| 69 | 206 | 69 | 1310 | 1926 | 208 | RESISTOR FIXED FILM |
| 92 | 89 | 13 | 121 | 112 | 26 | RESISTOR VARIABLE W |
| 69 | 118 | 4 | 44 | 46 | 8 | RESISTOR FIXED FILM |
| 73 | 189 | 174 | 1178 | 619 | 205 | RESISTOR FIXED FILM |
| 38 | 155 | 13 | 130 | 130 | 28 | RESISTOR FIXED COMP |
| 42 | 81 | 4 | 38 | 37 | 5 | RESISTOR FIXED FILM |
| 30 | 109 | 8 | 120 | 164 | 12 | RESISTOR FIXED FILM |
| 68 | 175 | 18 | 176 | 176 | 12 | RESISTOR FIXED COMP |
| 52 | 166 | 17 | 180 | 191 | 41 | RESISTOR FIXED FILM |
| 54 | 216 | 73 | 1960 | 3189 | 217 | RESISTOR FIXED FILM |
| 54 | 285 | 98 | 989 | 1001 | 365 | RESISTOR FIXED FILM |
| 55 | 139 | 5 | 130 | 209 | 11 | RESISTOR VARIABLE N |
| 63 | 270 | 1 | 11 | 23 | 4 | RESISTOR FIXED FILM |

## Histogram of Average Annual Demand
### Observations Averaged over Four Years



Annual Demand is highly skewed to the left, indicating many items with low annual demand.
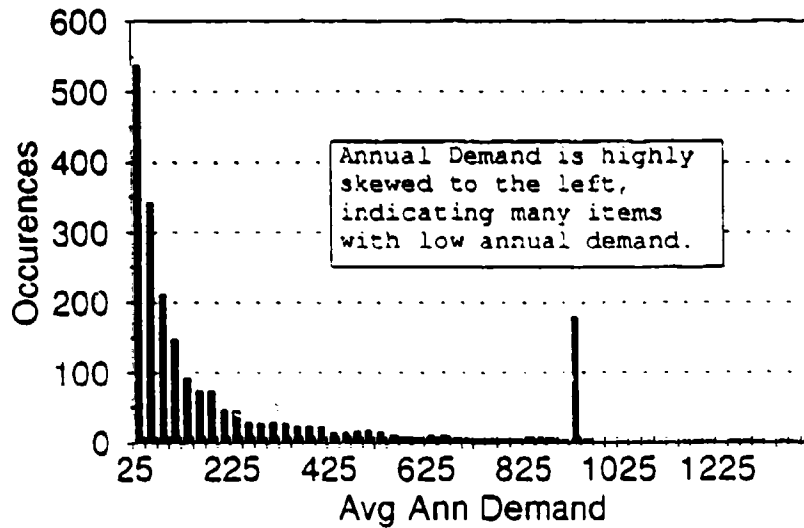
## Reduced Annual Demand Histogram
### Observations Avg < 900 Units



Annual Demand was restricted to less than 900 units to provide better visibility of the distribution. This graph is a subset of the above.

**Lead Time Histogram**
Total ALT and PLT Lead Time

Lead Time appears approximately lognormally distributed.
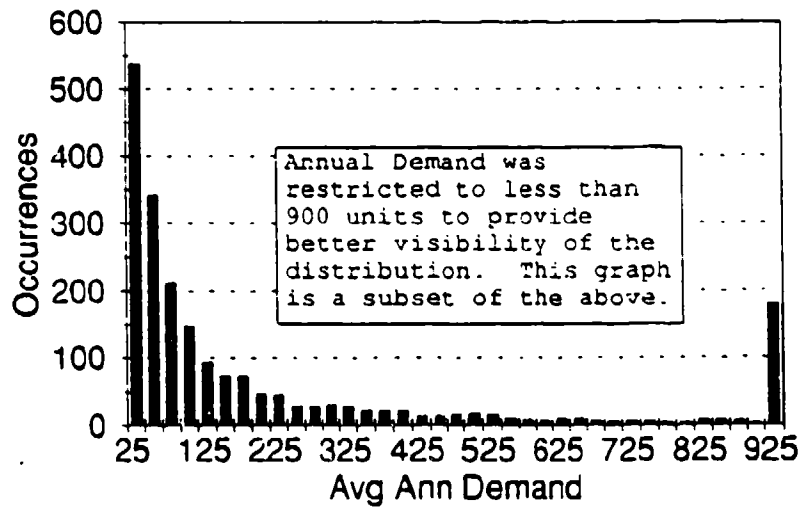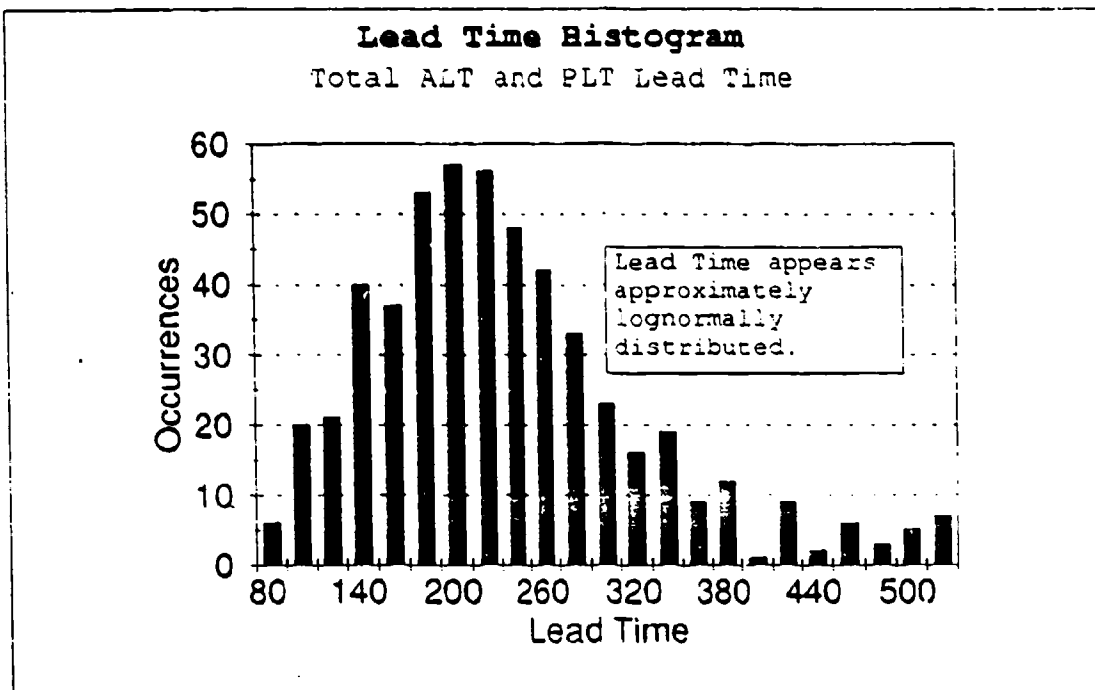
# Appendix C: Calculations of Levels for Each Factor

This appendix details the methods used to set the high, medium or mixed, and low levels for the demand pattern, annual demand, and lead time factors.

## Demand Pattern

As mentioned in Chapter III, the demand pattern was set as a percentage of DLA's total annual inventory that an activity uses as an economic order quantity. This quantity is the order size that DLA sees from the requesting activity when a replenishment order is placed. In this research, the number of activities placing demand on DLA was limited to four.

**First Level: High Order Quantities by All Activities.** Large order quantities by activities are a characteristic of infrequent orders being placed. An infrequent order was defined as an average of two orders per year. Keeping in mind that this study limits the requesting activities to four, the annual demand at each base can be defined as the annual demand at DLA divided by four (Eq. 1).

$$\text{Activity Annual Demand} = \text{DLA's Annual Demand} / 4 \qquad (1)$$

Given that the activity orders an average of twice per year, the order quantity placed by the activity can be expressed as a percentage of DLA's annual demand (Eq. 2).

$$
\begin{aligned}
\text{Activity Order Qty} &= \text{Activity Annual Demand} / 2 \\
&= (\text{DLA's Annual Demand} / 4) / 2 \\
&= (\text{DLA's Annual Demand}) / 8 \qquad\qquad (2) \\
&= .125 \text{ DLA's Annual Demand} \\
&= 12.5\% \text{ DLA's Annual Demand}
\end{aligned}
$$

Second Level: Low Order Quantities by All Activities. The percentage for low order quantities is calculated in the same manner as that for high order quantities. However, order frequency is set as once per month or 12 times per year in this situation instead of twice per year (Eq. 3).

$$
\begin{aligned}
\text{Activity Annual Demand} &= \text{DLA's Annual Demand} / 4 \\
\text{Activity Order Qty} &= \text{Activity Annual Demand} / 12 \\
&= (\text{DLA's Annual Demand} / 4) / 12 \\
&= (\text{DLA's Annual Demand}) / 48 \qquad\qquad (3) \\
&= .021 \text{ DLA's Annual Demand} \\
&= 2.1\% \text{ DLA's Annual Demand}
\end{aligned}
$$

Third Level: Mixed Order Quantities. Another level of the demand factor that the researchers wanted to consider was when two of the four activities displayed infrequent order quantities and at the same time the other two activities exhibit frequent order quantities. Intuitively, it would seem that two of the activities could be set at 12.5% and two could be set at 2.1%, using the calculations above. This could be the case if the holding, ordering, or

item cost was allowed to be different between the sets of
activities. The researchers, however, are considering the
activities to be Air Force bases that use an EOQ model to
set order quantities. It is therefore necessary to
calculate the percentages for the mixed order quantity
situation using the constraint of equal holding, ordering,
and item cost at the activity level. The steps of the
calculations follow but first the variables used in the
equations are defined.

$$R_I = \text{Infrequent Activity Annual Demand}$$
$$R_F = \text{Frequent Activity Annual Demand}$$
$$Q_I^* = \text{Order Qty for Infrequent Activity}$$
$$Q_F^* = \text{Order Qty for Frequent Activity}$$
$$O = \text{Activity Ordering Cost}$$
$$h = \text{Activity Holding Cost Factor}$$
$$P = \text{Item Cost}$$

Step One. From the EOQ model described in Chapter II,
annual demand divided by the order quantity yields the
number of orders placed per year. A frequent ordering
activity has been described as one that orders an average of
12 times per year while an infrequent activity orders an
average of twice per year. Based on the above fact and two
definitions, a solution for the annual demand at the sets of
activities can be calculated in terms of the activities'
order quantity (Eq. 4).

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$$\frac{R_I}{Q_I^\bullet} = 2 \quad \text{and} \quad \frac{R_F}{Q_F^\bullet} = 12 \tag{4}$$

$$R_I = 2Q_I^\bullet \quad \text{and} \quad R_F = 12Q_F^\bullet$$

**Step Two.** By substituting the EOQ formula in for the order quantities above, the equations can be simultaneously reduced to equations for the item cost (Eq. 5).

$$R_I = 2\sqrt{\frac{2R_I O}{Ph}} \qquad R_F = 12\sqrt{\frac{2R_F O}{Ph}}$$

$$\left(\frac{R_I}{2}\right)^2 = \frac{2R_I O}{Ph} \qquad \left(\frac{R_F}{12}\right)^2 = \frac{2R_F O}{Ph} \tag{5}$$

$$\frac{R_I}{8} = \frac{O}{Ph} \qquad \frac{R_F}{288} = \frac{O}{Ph}$$

$$P = \frac{8O}{R_I h} \qquad P = \frac{288O}{R_F h}$$

**Step Three.** Now the item cost, P, for both the equations above should be equal. In other words, the two equations can be set equal to one another and the annual demand for one set of activities can be solved for in terms of the annual demand for the other set of activities (Eq. 6).

$$\frac{8O}{R_I h} = \frac{288O}{R_F h}$$

$$\frac{8}{R_I} = \frac{288}{R_F} \tag{6}$$

$$8R_F = 288R_I$$

$$R_I = .02\overline{7}R_F$$

**Step Four.** Now, DLA's total annual demand has to equal the sum of the infrequent activities' demand and the frequent activities' demand (Eq. 7).

$$R = R_I + R_F \text{, substituting:}$$
$$R = .02\overline{7}R_F + R_F = 1.02\overline{7}R_F \qquad (7)$$
$$R_F = .973R$$

If the set of activity's total demand is divided by the frequency of orders now, the percentage of DLA's total demand that represents the order quantity for both of the frequent activities combined is revealed. To get the percentage for one activity, the combined percentage must be divided by the number of activities or 2 in this case (Eq. 8).

$$2Q_F^* = \frac{R_F}{12} = \frac{.973R}{12} = .081R = 8.1\%R$$
$$Q_F^* = \frac{8.1\%}{2}R = 4.05\%R \approx 4.1\%R \qquad (8)$$

Step Five. The same steps can be taken to solve for the infrequent activity order quantity now (Eq. 9).

$$R_I = .02\overline{7}R_F$$
$$R_F = 36R_I$$
$$R = 36R_I + R_I = 37R_I$$
$$R_I = .027R \qquad (9)$$
$$2Q_I^* = \frac{R_I}{2} = \frac{.027}{2}R \approx 1.4\%R$$
$$Q_I^* = \frac{1.4\%}{2}R = .7\%R$$

This concludes the steps for calculating the levels for the demand pattern experimental factor.

## Total Annual Demand at DLA

The levels for total annual demand were established through analysis of the collected data. Yearly demand values were averaged over a four year period and a histogram of these values was made (page 83). As evident by the histogram, the annual demand values are skewed extremely to the right. Due to this, the low level for this factor was set at the median of all of the observed averages. The medium level was then set as the mean of the averages and the high level was picked as the middle value of the largest values. The group of largest values was taken to be the upper 10% of all observed averages. Picking the middle value from this range helped to avoid a bias that may have been caused had the largest value been taken.

## Total Lead Time for DLA Items

Lead time levels were obtained using the same type method as that used to obtain annual demand values. A histogram of the lead times from the observed data was constructed (page 84). Based on this histogram, a low level for lead times was set as the middle value of the bottom 10% of all lead times. The middle level was set as the median value of all times and a high level was obtained by taking the middle value from the largest 10% of all lead times.

## Appendix D: Model Translation and Description

This appendix provides a step by step, detailed analysis of the simulation model. Each module of FORTRAN coding is explained. Also, the different models based on the time between creations for the activities are listed.

SLAM Model 1 (All Activities Order Frequently): The network for this model follows:

```
GEN, CAPT LONG, CONTROL 1,7/27/1994,30,Y,Y,Y/Y,Y,Y/1,72;
LIMITS,,10,4500;
```

```
Establishes the model to run 30 times for 11000 time units each
and sets attribute limits at 10 and entity limits at 4500.
```

```
INITIALIZE,,11000,Y,Y,Y;
```

```
TIMST,XX(5),AVG OH INV,10/-50/50;
```

```
Measures on hand balance (XX(5)) in a time persistent manner.
```

```
NETWORK;
;
BAS1    CREATE,USERF(1),,1;
QSZ1    ASSIGN,ATRIB(2)=USERF(3);
```

```
Assigns the first activity time between creations of USERF(1) and
EOQ size USERF(3). These user functions will be explained in the
FORTRAN description.
```

```
DLA     ASSIGN,XX(9)=XX(9)+ATRIB(2);
        COLCT(5),ATRIB(2),DEM DISTR;
DECI    ASSIGN,XX(5)=XX(5)-ATRIB(2);
```

```
Increases the demand placed on DLA by the EOQ size, tracks the
demand size to ensure the USERF worked as intended, and decreases
the on hand balance by the activity EOQ size.
```

```
        EVENT,3;
```

```
Calculates if the reorder point or subsequent reorder point level
has been breached. If it has a flag (ATRIB(5)) is set to trigger
replenishment.
```

```
ACTIVITY,,ATRIB(5).GE.0.5;
```

```
        ACTIVITY,,,END;
```

```
        ASSIGN,XX(11)=XX(11)+1;
           ACTIVITY,XX(4);
```

If the flag is set, the replenishment counter, XX(11) is increased by
one and it takes the set lead time, XX(4), for the order to arrive at
the inventory center.


The inventory position right before the replenishment arrives is
observed and tracked.

```
LOOKY COLCT(2),XX(5),PREREPL INV POS,10/-15.0/3.0;
```


The on hand balance, XX(5), is increased by DLA's EOQ quantity,
XX(7). Also, the number of orders, XX(8), is increased by one.

```
REPL   ASSIGN,XX(5)=XX(5)+XX(7),XX(8)=XX(8)+1;

        COLCT(6),XX(6),NUM ORDERS;
        ASSIGN,XX(11)=XX(11)-1;
```

The replenishment counter, XX(11) is decreased by one.

```
        EVENT,4;
```

Event 4 resets the array that tracks the level of replenishment to
zero.

```
END    TERMINATE;
```

The entity is terminated. This is the termination node that all
entities end at eventually.

```
BAS2   CREATE,USERF(1),3,1;
QSZ2   ASSIGN,ATRIB(2)=USERF(3);
        ACTIVITY,,,DLA;
```

Assigns the second activity time between creations of USERF(1) and
EOQ size USERF(3). These user functions will be explained in the
FORTRAN description.

```
BAS3   CREATE,USERF(1),6,1;
QSZ3   ASSIGN,ATRIB(2)=USERF(4);
        ACTIVITY,,,DLA;
```

Assigns the third activity time between creations of USERF(1) and
EOQ size USERF(4). These user functions will be explained in the
FORTRAN description.

```
BAS4   CREATE,USERF(1),9,1;
QSZ4   ASSIGN,ATRIB(2)=USERF(4);
        ACTIVITY,,,DLA;
```

```
Assigns the fourth activity time between creations of USERF(1) and
EOQ size USERF(4).  These user functions will be explained in the
FORTRAN description.
```

MONTH CREATE,3,3,1;
```
Creates an entity every quarter to trigger the quarterly forecasted
demand and economic order quantity calculations.
```

CALC   EVENT;
```
Event 1 calculates the QFD and EOQ values to be used.
```

        EVENT,2,1;
```
Event 2 tracks and calculates the averages that were used to
eliminate initialization bias and to track average annual orders.
```

```
            ACTIVITY,,ATRIB(7).EQ.1;
            ACTIVITY,,,END;
        COLCT(3),,ATRIB(3),AVG QTR OH BAL,;
        COLCT(4),ATRIB(4),AVG ANN ORDERS,10/0.0/1;
            ACTIVITY,,,END;
```

```
Collects the averages calculated in Event 2 to eliminate
initialization bias.
```

        END;
```
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,1048015(3),2236846(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,2413048(3),4216793(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,3757039(3),7792106(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,9956272(3),9630191(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,8957914(3),8547536(9);
SIMULATE;
```

```
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,2891869(3),6355340(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0942993(3),1036561(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0711997(3),5108512(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0236821(3),0101154(9);        •
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,5216253(3),0705697(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,4866391(3),5416458(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,3263932(3),2933427(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0248833(3),8152572(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,2967620(3),0074257(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
```

```
SEEDS,0536604(3),9192126(9);
SIMULATE;
;
INTLC,XX(1)=.021,.X(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0058204(3),0072569(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,2597657(3),0976383(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,9156742(3),1795556(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MCNTR,CLEAR,8000;
SEEDS,4650318(3),9215789(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,1501101(3),5360201(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,1876479(3),1646691(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,7914194(3),6259046(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,5732559(3),5853933(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0995891(3),9827982(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
```

```
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,5340293(3),9654836(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,0225279(3),7265763(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,J364809(3),1517924(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,8304934(3),0930930(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
SEEDS,6243616(3),8007856(9);
SIMULATE;
;
INTLC,XX(1)=.021,XX(2)=.021,XX(3)=70,XX(4)=3.26667;
INTLC,XX(5)=10,XX(7)=10,XX(10)=855.77,XX(11)=1;
MONTR,CLEAR,8000;
```

> Each of the thirty groups of lines above, initialize the variables
> that need initializing before each run. Appendix E. describes these
> variables and why they are initialized in more detail. The
> statistical arrays are then set to clear at time 8000 and data is
> collected for the remaining 3000 months. A seeds statement is
> assigned to allow common random number to be used between treatments.

```
SEEDS,785616(3),3944053(9);

FIN;
```

SLAM Model 2 (Two Activities Order Frequently/Two
Infrequently): The only difference between this network and
the last has to do with the creation and assign nodes for
the activities. Therefore only those different nodes will
be presented. Those nodes are:

```
BAS1   CREATE,USERF(2),,1;
QSZ1   ASSIGN,ATRIB(2)=USERF(3);
```

> **Assigns the first activity time between creations of USERF(2) and
> EOQ size USERF(3).  These user functions will be explained in the
> FORTRAN description.**

```
BAS2   CREATE,USERF(2),3,1;
QSZ2   ASSIGN,ATRIB(2)=USERF(3);
       ACTIVITY,,,DLA;
```

> **Assigns the second activity time between creations of USERF(2) and
> EOQ size USERF(3).  These user functions will be explained in the
> FORTRAN description.**

```
BAS3   CREATE,USERF(1),6,1;
QSZ3   ASSIGN,ATRIB(2)=USERF(4);
       ACTIVITY,,,DLA;
```

> **Assigns the third activity time between creations of USERF(1) and
> EOQ size USERF(4).  These user functions will be explained in the
> FORTRAN description.**

```
BAS4   CREATE,USERF(1),9,1;
QSZ4   ASSIGN,ATRIB(2)=USERF(4);
       ACTIVITY,,,DLA;
```

> **Assigns the fourth activity time between creations of USERF(1) and
> EOQ size USERF(4).  These user functions will be explained in the
> FORTRAN description.**

SLAM Model 3 (All Activities Order Infrequently):  The
only difference between this network and the last has to do
with the creation and assign nodes for the activities.
Therefore only those different nodes will be presented.
Those nodes are:

```
BAS1   CREATE,USERF(2),,1;
QSZ1   ASSIGN,ATRIB(2)=USERF(3);
```

> **Assigns the first activity time between creations of USERF(2) and
> EOQ size USERF(3).  These user functions will be explained in the
> FORTRAN description.**

```
BAS2   CREATE,USERF(2),3,1;
QSZ2   ASSIGN,ATRIB(2)=USERF(3);
       ACTIVITY,,,DLA;
```

> **Assigns the first activity time between creations of USERF(2) and
> EOQ size USERF(3).  These user functions will be explained in the
> FORTRAN description.**

```
BAS3   CREATE,USERF(2),6,1;
QSZ3   ASSIGN,ATRIB(2)=USERF(4);
       ACTIVITY,,,DLA;
```

> **Assigns the first activity time between creations of USERF(2) and
> EOQ size USERF(4). These user functions will be explained in the
> FORTRAN description.**

```
BAS4   CREATE,USERF(2),9,1;
QSZ4   ASSIGN,ATRIB(2)=USERF(4);
       ACTIVITY,,,DLA;
```

> **Assigns the first activity time between creations of USERF(2) and
> EOQ size USERF(4). These user functions will be explained in the
> FORTRAN description.**

Model FORTRAN User Written Functions: User written
subroutines and functions were a key element of the
simulation model. Below is the line by line FORTRAN code
that was constructed and a description of what each set of
lines of code is designed to do:

```
PROGRAM MAIN
 DIMENSION NSET(1500000)
 PARAMETER   (MEQT=100,   MSCND=25,   MENTR=25,   MRSC=75,   MARR=50,
1 MGAT=25,    MHIST=50,   MCELS=500,  MCLCT=50,   MSTAT=50,   MEQV=100,
2 MATRB=100,  MFILS=100,  MPLOT=10,   MVARP=10,   MSTRM=10,
3 MACT=100,   MNODE=500,  MITYP=50,   MMXXV=100)
 PARAMETER (MVARP1=MVARP+1)
 COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
1 MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
2 SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
 COMMON QSET(1500000)
 EQUIVALENCE (NSET(1),QSET(1))
 NNSET=1500000
 NCRDR=5
 NPRNT=6
 NTAPE=7
 OPEN(1,FILE='GIM94S:[WLONG.THESIS_MODEL.TAPE]IRESULTS.DAT',
1 STATUS='OLD', ACCESS='APPEND')
 CALL SLAM
 STOP
```

> **Program Main is common to any user written code. This block tells
> the computer how to interface with SLAM II. Also, it calls the
> program and opens a file to write output data to.**

```
          END

C
C          SUBROUTINE CALCULATES THE QFD, ROP, AND DLA EOQ FOR THE MODEL
C          ALSO, CALCULATES THE AVG QTR OH BAL, AND ANN ORDERS
C
          SUBROUTINE EVENT(IFN)
          PARAMETER   (MEQT=100,   MSCND=25,   MENTR=25,   MRSC=75,   MARR=50,
         1 MGAT=25,     MHIST=50,   MCELS=500,  MCLCT=50,   MSTAT=50,  MEQV=100,
         2 MATRB=100,  MFILS=100,  MPLOT=10,   MVARP=10,   MSTRM=10,
         3 MACT=100,   MNODE=500,  MITYP=50,   MMXXV=100)
          PARAMETER  (MVARP1=MVARP+1)
          COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
         1 MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
         2 SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
          COMMON/UCOM1/A(100),ANNDEM,RUNTOT,TEMPT,SINGLF,TWICEF
C
          GOTO (1,2,3,4),IFN
C         QFD, EOQ, AND ROP ROUTINE
C
1         SINGLF=(.1*XX(9))+(.9*SINGLF)
          TWICEF=(.1*(SINGLF-TWICEF))+TWICEF
          QFD=(2.0*SINGLF)-TWICEF
          IF (QFD.LT.0) THEN
              QFD=0.0
          ENDIF
          IDLAEOQ=INT(69.0*SQRT(QFD/XX(10)))
          IF (IDLAEOQ.LT.QFD) THEN
              IDLAEOQ=INT(QFD)
          ENDIF
          XX(7)=IDLAEOQ
          XX(6)=(XX(4)/3)*QFD
          XX(9)=0.0
          RETURN
```

> **Event 1** uses DLA's double exponential forecasting method to calculate a
> quarterly forecasted demand (QFD). The demand placed on the inventory
> center is stored in variable XX(9). Each quarter this variable is used
> in the QFD calculation and then cleared. The QFD is then used to
> calculate the EOQ for the inventory center.

```
C
C          QTR DEMAND AVG AND ANN ORDERS ROUTINE
C
2         ANNDEM=XX(5)+ANNDEM
          XX(12)=XX(12)+1.0
          IF (XX(12).EQ.4.0) THEN
              QTRAVGDEM=(ANNDEM/XX(12))
              TEMPY=ANNDEM+TEMPY
              XX(13)=XX(13)+1.0
              IF (XX(13).EQ.4.0) THEN
                  XX(14)=TEMPY/4.0
                  XX(13)=0.0
                  TEMPY=0.0
              ENDIF
              ATRIB(3)=QTRAVGDEM
```

```
          ANNDEM=0.0
          XX(12)=0.0
          ATRIB(4)=XX(8)-TEMP1
          TEMPO=(XX(8)-TEMPT)+TEMPO
          TEMPT=XX(8)
          XX(15)=XX(15)+1.0
          IF (XX(15).EQ.4.0) THEN
              XX(16)=TEMPO/4.0
              XX(15)=0.0
              TEMPO=0.0
          ENDIF
          ATRIB(7)=1.0
      ENDIF
      RETURN
```

> **Event 2 uses the on hand balance, XX(5), and the total number of orders, XX(8), to calculate averages for elimination of initialization bias. This event was a major player in the pilot runs but served only minor purposes in the actual data collection runs.**

```
C
C      CALCULATES MULTIPLE REQUISITIONS DURING THE SAME ORDER CYCLE
C
3      CONTINUE
       RLEVQTY=XX(6)-(XX(7)*(XX(11)-1.))
       IF (XX(5).LT.RLEVQTY) THEN
           IF (A(XX(11)).LT.1.) THEN
               A(XX(11))=1.0
               ATRIB(5)=1.0
               ATRIB(6)=XX(11)
           ENDIF
       ENDIF
C
       RETURN
```

> **Event 3 was used to simulate the actions one would expect from an item manager if backorders were continuing to grow. The way it works is a requisition is placed when the reorder point is breached. If a negative balance occurs that dips below the total quantity one would expect to be consumed before the reorder point would be exceeded again, a second requisition is placed with the vendor and so on.**

```
C
C      RESETS A(ATRIB(6)) TO 0
C
4      A(ATRIB(6))=0.0
       RETURN
C

       END
```

> **Event 4 resets the array that tracks what requisition level the system is on in Event 3. This allows the process to continue working.**

```
C
C      THIS SUBROUTINE RESETS ARRAY A() AT THE START OF EVERY RUN
C
```

```
          SUBROUTINE INTLC
          COMMON/UCOM1/A(100),ANNDEM,RUNTOT,TEMPT,SINGLF,TWICEF
C
          DO 100 I=1,100
              A(I) = 0.0
100       CONTINUE
          ANNDEM=0.0
          RUNTOT=0.0
          TEMPT=0.0
          SINGLF=0.0
          TWICEF=0.0
          RETURN
          END
```

Subroutine INTLC is read by SLAM II at the start of every run.  Its
function is to reset all of the FORTRAN local variables at the
beginning of every run.

```
C
C         THIS SUBROUTINE WRITES OUTPUT TO A FILE
C
          SUBROUTINE OTPUT
          COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
         1 MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
         2 SSL(100),TNEXT,TNOW,XX(100)
C
C         SETUP OUTPUT FOR ANALYSIS
C
          IF (XX(1).EQ.0.021) THEN
              LVL1=1
          ENDIF
          IF (XX(1).EQ.0.007) THEN
              LVL1=2
          ENDIF
          IF (XX(1).EQ.0.125) THEN
              LVL1=3
          ENDIF
          IF (XX(4).EQ.3.26667) THEN
              LVL2=1
          ENDIF
          IF (XX(4).EQ.7.0) THEN
              LVL2=2
          ENDIF
          IF (XX(4).EQ.14.4) THEN
              LVL2=3
          ENDIF
          IF (XX(3).EQ.70.0) THEN
              LVL3=1
          ENDIF
          IF (XX(3).EQ.481.0) THEN
              LVL3=2
          ENDIF
          IF (XX(3).EQ.3750.0) THEN
              LVL3=3
          ENDIF
          LCON=1+(LVL1-1)+(3*(LVL2-1))+(9*(LVL3-1))
1000      FORMAT(' ',' CON ',I2,'   RUN      PRE-REPL INV     AVG OH INV',
         1 '      AVG ANN ORD        ')
```

```
1100    FORMAT(' ','              ',I2,F18.4,F16.4,F13.4)
        IF (NNRUN.EQ.1) THEN
           WRITE(1,1000) LCON
        ENDIF
        IRUN=IRUN+1
        OUT2=CCAVG(2)
        OUT3=TTAVG(1)
        OUT4=CCAVG(4)
        WRITE(1,1100) IRUN,OUT2,OUT3,OUT4
        RETURN
        END
```

> Subroutine OTPUT writes the output data for all runs to a file that
> can be imported into a spreadsheet or statistics program.  This
> greatly eases in the analysis of the output data.

```
C
C       VARIOUS USERFS FOR TIME BETWEEN CREATIONS AND BASE EOQ SIZE
C
        FUNCTION USERF(IFN)
        PARAMETER  (MEQT=100,  MSCND=25,  MENTR=25,  MRSC=75,  MARR=50,
       1 MGAT=25,    MHIST=50,  MCELS=500, MCLCT=50,  MSTAT=50, MEQV=50,
       2 MATRB=100, MFILS=100, MPLOT=10,  MVARP=10,  MSTRM=10,
       3 MACT=100,  MNODE=500, MITYP=50,  MMXXV=100)
        COMMON/SCOM1/ATRIB(MATRB), DD(MEQT), DDL(MEQT), DTNOW, II, MFA,
       1 MSTOP, NCLNR, NCRDR, NPRNT, NNRUN, NNSET, NTAPE, SS(MEQT),
       2 SSL(MEQT), TNEXT, TNOW, XX(MMXXV)
        GOTO (1,2,3,4),IFN
C
C       CALCULATE TIME BETWEEN CREATIONS USING A BETA DISTRIBUTION
C       FOR FREQUENT ORDERING BASES
C
1       TBCFRQ=BETA(2.0,2.0,9)+.5
        USERF=TBCFRQ
        RETURN
```

> USERF(1) calculates a time between creation for an activity that is
> represented by the beta distribution.  The mean time is 1 month with
> a min of .5 and a max. of 1.5.  Any activity may use this function
> based on the frequency of its orders.

```
C
C       CALCULATE TIME BETWEEN CREATIONS USING A BETA DISTRIBUTION
C       FOR INFREQUENT ORDERING BASES
C
2       TBCINF=BETA(2.0,2.0,9)*6+3.0
        USERF=TBCINF
        RETURN
```

> USERF(2) calculates a time between creation for an activity that is
> represented by the beta distribution.  The mean time is 6 month with
> a min of 3 and a max. of 9.  Any activity may use this function based
> on the frequency of its orders.

```
C
C       CALCULATE THE BASE EOQ SIZE FOR BASES 1 AND 2
C
3       QEOQ12=XX(1)*XX(3)
```

```
        TEMP1=QEOQ12-REAL(INT(QEOQ12))
        RANDOM1=UNFRM(0.0,1.0,3)
        USERF=REAL(INT(QECQ12))
        IF (RANDOM1.LT.TEMP1) THEN
            USERF=USERF+1.0
        ENDIF
        RETURN
```

> **USERF(3)** uses the value XX(1), which represents the demand pattern for
> the activity, and the value XX(3), which represents the annual demand
> placed on DLA, to calculate the EOQ quantity size for the activity.
> XX(1) is initialized and is used only by activities 1 and 2.
> Therefore, this function is used only by activities 1 and 2.  XX(3) is
> used by all activities.

```
C
C       CALCULATE THE BASE EOQ SIZE FOR BASES 3 AND 4
C
4       QEOQ34=XX(2)*XX(3)
        TEMP2=QEOQ34-REAL(INT(QEOQ34))
        RANDOM2=UNFRM(0.0,1.0,3)
        USERF=REAL(INT(QEOQ34))
        IF (RANDOM2.LT.TEMP2) THEN
            USERF=USERF+1.0
        ENDIF
        RETURN
```

> **USERF(4)** uses the value XX(2), which represents the demand pattern for
> the activity, and the value XX(3), which represents the annual demand
> placed on DLA, to calculate the EOQ quantity size for the activity.
> XX(2) is initialized and is used only by activities 3 and 4.
> Therefore, this function is used only by activities 3 and 4.  XX(3) is
> used by all activities.

```
        END
```

# Appendix E: Control Deck Initializations

## Global Variable Glossary

|   | Variable | Definition |
|---|----------|------------|
| 1 | XX(1) | Demand Pattern percentage for activities 1 & 2 |
| 2 | XX(2) | Demand Pattern percentage for activities 3 & 4 |
| 3 | XX(3) | Annual demand placed on DLA |
| 4 | XX(4) | Lead Time from vendor to DLA |
| 5 | XX(5) | Inventory on-hand balance for DLA |
| 6 | XX(7) | Economic Order Quantity for DLA |
| 7 | XX(10) | Price per item |

Three variations of the same model were employed to facilitate differences in demand pattern order represented in the model as time between creations. Treatments with infrequent orders are represented with an I, frequent orders an F, and M, denotes mixed frequency occurrence.

Global variable XX(4) was calculated by taking the Lead Time from collected data represented in days and dividing by 90 to convert them into quarters. Appendix C shows calculations for lead times are given in detail. Variable XX(10) represents the price of the item derived using the EOQ equation and known components as indicated below.

$$Q^* = \sqrt{\frac{2RC}{hP}} \qquad \text{becomes} \qquad P = \frac{2RC}{hQ^{*2}}$$

Where,

P = Price of an item

R = Annual demand levels defined as either: 70, 481 or 3750. See appendix C for methodology.

C = $5.20 Defined by Air Force as the fixed ordering cost.

h = 10% Defined by Air Force as the fixed holding cost percentage.

$Q^*$ = Calculated. See appendix C.

All other variables are discussed in appendix C, Calculations of Levels for Each Factor. The spreadsheets on the following pages show the initialized values used for each variable and treatment.

# Defense Logistic Agency Economic Order Quantity

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Var | DLAEOQF | DLAEOQM | DLAEOQI | DLAEOQF | DLAEOQM | DLAEOQI |
| XX(1) | 0.021 | 0.007 | 0.125 | 0.021 | 0.007 | 0.125 |
| XX(2) | 0.021 | 0.041 | 0.125 | 0.021 | 0.041 | 0.125 |
| XX(3) | 70 | 70 | 70 | 70 | 70 | 70 |
| XX(4) | 3.26667 | 3.26667 | 3.26667 | 7 | 7 | 7 |
| XX(5) | 10 | 14 | 59 | 10 | 14 | 59 |
| XX(7) | 10 | 14 | 59 | 10 | 14 | 59 |
| XX(10) | 855.77 | 440.21 | 23.77 | 855.77 | 440.21 | 23.77 |

| | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|
| Var | DLAEOQF | DLAEOQM | DLAEOQI | DLAEOQF | DLAEOQM | DLAEOQI |
| XX(1) | 0.021 | 0.007 | 0.125 | 0.021 | 0.007 | 0.125 |
| XX(2) | 0.021 | 0.041 | 0.125 | 0.021 | 0.041 | 0.125 |
| XX(3) | 70 | 70 | 70 | 481 | 481 | 481 |
| XX(4) | 14.4 | 14.4 | 14.4 | 3.26667 | 3.26667 | 3.26667 |
| XX(5) | 10 | 14 | 59 | 68 | 95 | 407 |
| XX(7) | 10 | 14 | 59 | 68 | 95 | 407 |
| XX(10) | 855.77 | 440.21 | 23.77 | 124.54 | 64.06 | 3.46 |

# Defense Logistic Agency Economic Order Quantity

|         | 13      | 14      | 15      | 16      | 17      | 18      |
|---------|---------|---------|---------|---------|---------|---------|
| Var     | DLAEOQF | DLAEOQM | DLAEOQI | DLAEOQF | DLAEOQM | DLAEOQI |
| XX(1)   | 0.021   | 0.007   | 0.125   | 0.021   | 0.007   | 0.125   |
| XX(2)   | 0.021   | 0.041   | 0.125   | 0.021   | 0.041   | 0.125   |
| XX(3)   | 481     | 481     | 481     | 481     | 481     | 481     |
| XX(4)   | 7       | 7       | 7       | 14.4    | 14.4    | 14.4    |
| XX(5)   | 68      | 95      | 407     | 68      | 95      | 407     |
| XX(7)   | 68      | 95      | 407     | 68      | 95      | 407     |
| XX(10)  | 124.54  | 64.06   | 3.46    | 124.54  | 64.06   | 3.46    |

|         | 19      | 20      | 21      | 22      | 23      |
|---------|---------|---------|---------|---------|---------|
| Var     | DLAEOQF | DLAEOQM | DLAEOQI | DLAEOQF | DLAEOQM |
| XX(1)   | 0.021   | 0.007   | 0.125   | 0.021   | 0.007   |
| XX(2)   | 0.021   | 0.041   | 0.125   | 0.021   | 0.041   |
| XX(3)   | 3750    | 3750    | 3750    | 3750    | 3750    |
| XX(4)   | 3.26667 | 3.26667 | 3.26667 | 7       | 7       |
| XX(5)   | 529     | 737     | 3172    | 529     | 737     |
| XX(7)   | 529     | 737     | 3172    | 529     | 737     |
| XX(10)  | 15.97   | 8.22    | 0.44    | 15.97   | 8.22    |

## Defense Logistic Agency Economic Order Quantity

|        | 24      | 25      | 26      | 27      |
|--------|---------|---------|---------|---------|
| Var    | DLAEOQI | DLAEOQF | DLAEOQM | DLAEOQI |
| XX(1)  | 0.125   | 0.021   | 0.007   | 0.125   |
| XX(2)  | 0.125   | 0.021   | 0.041   | 0.125   |
| XX(3)  | 3750    | 3750    | 3750    | 3750    |
| XX(4)  | 7       | 14.4    | 14.4    | 14.4    |
| XX(5)  | 3172    | 529     | 737     | 3172    |
| XX(7)  | 3172    | 529     | 737     | 3172    |
| XX(10) | 0.44    | 15.97   | 8.22    | 0.44    |

## Appendix F: Model Parameters and Expected Values

In this appendix, the expected values DLA would experience with 'perfect knowledge' of annual demand is presented in tabular form. Model parameters were discussed in Appendix C.

Under the headings of lead time values, annual demand values and base EOQ patterns, values for each treatment of annual demand is given. With this information DLA should experience the values for EOQ, ordering cost, holding cost and total variable cost as shown.

Before the DLA model results with continuous demand values could be calculated, a table of base order quantities and calculated item costs were constructed and the table is also included in this appendix. Additionally, to calculate DLA model results, a table of DLA's old and new T-values are given as expressed by research analysts at DESC.

# Factorial Design and DLA Model Benchmark Results
## Baseline for DLA without Classic EOQ Assumption Violations

| Lead Time Values | Annual Demand Values | Base EOQ Patterns | | | | DLA Model Results with Continuous Demand | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Base 1 | Base 2 | Base 3 | Base 4 | EOQ | Ordering Cost | Holding Cost | Tot Var Cost |
| 98 | 70 | 2.1% | 2.1% | 2.1% | 2.1% | 10 | 675.52 | 675.52 | $1,351.04 |
| 98 | 70 | 0.7% | 0.7% | 4.1% | 4.1% | 14 | 484.49 | 484.49 | $968.99 |
| 98 | 70 | 12.5% | 12.5% | 12.5% | 12.5% | 59 | 112.59 | 112.59 | $225.17 |
| 98 | 481 | 2.1% | 2.1% | 2.1% | 2.1% | 68 | 675.52 | 675.52 | $1,351.04 |
| 98 | 481 | 0.7% | 0.7% | 4.1% | 4.1% | 95 | 484.49 | 484.49 | $968.99 |
| 98 | 481 | 12.5% | 12.5% | 12.5% | 12.5% | 407 | 112.59 | 112.59 | $225.17 |
| 98 | 3750 | 2.1% | 2.1% | 2.1% | 2.1% | 529 | 675.52 | 675.52 | $1,351.04 |
| 98 | 3750 | 0.7% | 0.7% | 4.1% | 4.1% | 737 | 484.49 | 484.49 | $968.99 |
| 98 | 3750 | 12.5% | 12.5% | 12.5% | 12.5% | 3172 | 112.59 | 112.59 | $225.17 |
| 210 | 70 | 2.1% | 2.1% | 2.1% | 2.1% | 10 | 675.52 | 675.52 | $1,351.04 |
| 210 | 70 | 0.7% | 0.7% | 4.1% | 4.1% | 14 | 484.49 | 484.49 | $968.99 |
| 210 | 70 | 12.5% | 12.5% | 12.5% | 12.5% | 59 | 112.59 | 112.59 | $225.17 |
| 210 | 481 | 2.1% | 2.1% | 2.1% | 2.1% | 68 | 675.52 | 675.52 | $1,351.04 |
| 210 | 481 | 0.7% | 0.7% | 4.1% | 4.1% | 95 | 484.49 | 484.49 | $968.99 |
| 210 | 481 | 12.5% | 12.5% | 12.5% | 12.5% | 407 | 112.59 | 112.59 | $225.17 |
| 210 | 3750 | 2.1% | 2.1% | 2.1% | 2.1% | 529 | 675.52 | 675.52 | $1,351.04 |
| 210 | 3750 | 0.7% | 0.7% | 4.1% | 4.1% | 737 | 484.49 | 484.49 | $968.99 |
| 210 | 3750 | 12.5% | 12.5% | 12.5% | 12.5% | 3172 | 112.59 | 112.59 | $225.17 |
| 432 | 70 | 2.1% | 2.1% | 2.1% | 2.1% | 10 | 675.52 | 675.52 | $1,351.04 |
| 432 | 70 | 0.7% | 0.7% | 4.1% | 4.1% | 14 | 484.49 | 484.49 | $968.99 |
| 432 | 70 | 12.5% | 12.5% | 12.5% | 12.5% | 59 | 112.59 | 112.59 | $225.17 |
| 432 | 481 | 2.1% | 2.1% | 2.1% | 2.1% | 68 | 675.52 | 675.52 | $1,351.04 |
| 432 | 481 | 0.7% | 0.7% | 4.1% | 4.1% | 95 | 484.49 | 484.49 | $968.99 |
| 432 | 481 | 12.5% | 12.5% | 12.5% | 12.5% | 407 | 112.59 | 112.59 | $225.17 |
| 432 | 3750 | 2.1% | 2.1% | 2.1% | 2.1% | 529 | 675.52 | 675.52 | $1,351.04 |
| 432 | 3750 | 0.7% | 0.7% | 4.1% | 4.1% | 737 | 484.49 | 484.49 | $968.99 |
| 432 | 3750 | 12.5% | 12.5% | 12.5% | 12.5% | 3172 | 112.59 | 112.59 | $225.17 |

| Lead Time Values (Days) | |
|---|---|
| Low = (average of the bottom 10% of raw data) = | 98 |
| Med = (median of the raw data) = | 210 |
| High = (average of the top 10% of the raw data) = | 432 |

| Annual Demand Values (Units) | |
|---|---|
| Low = (median of the raw data) = | 70 |
| Med = (mean of the raw data) = | 481 |
| High = (average of the top 10% of the raw data) = | 3750 |

| Base EOQ Percentages | |
|---|---|
| Low EOQ = High Frequency = One order per month = | 2.10% |
| Mixed EOQ = 2 Hi Freq = One order per month = | 4.10% |
| = 2 Lo Freq = Two orders per year = | 0.70% |
| High EOQ = Low Frequency = Two orders per year = | 12.50% |

| Patterns |
|---|
| 2.1, 2.1, 2.1, 2.1 |
| .07, .07, 4.1, 4.1 |
| 12.5, 12.5, 12.5, 12.5 |

## Base Order Quantities and Calculated Item Cost

| Base 1 EOQ Qty | Base 2 EOQ Qty | Base 3 EOQ Qty | Base 4 EOQ Qty | Item $ |
|---|---|---|---|---|
| 1.46 | 1.46 | 1.46 | 1.46 | $855.77 |
| 0.47 | 0.47 | 2.84 | 2.84 | $440.21 |
| 8.75 | 8.75 | 8.75 | 8.75 | $23.77 |
| 10.02 | 10.02 | 10.02 | 10.02 | $124.54 |
| 3.25 | 3.25 | 19.50 | 19.50 | $64.06 |
| 60.13 | 60.13 | 60.13 | 60.13 | $3.46 |
| 78.12 | 78.12 | 78.12 | 78.12 | $15.97 |
| 25.31 | 25.31 | 152.03 | 152.03 | $8.22 |
| 468.75 | 468.75 | 468.75 | 468.75 | $0.44 |
| 1.46 | 1.46 | 1.46 | 1.46 | $855.77 |
| 0.47 | 0.47 | 2.84 | 2.84 | $440.21 |
| 8.75 | 8.75 | 8.75 | 8.75 | $23.77 |
| 10.02 | 10.02 | 10.02 | 10.02 | $124.54 |
| 3.25 | 3.25 | 19.50 | 19.50 | $64.06 |
| 60.13 | 60.13 | 60.13 | 60.13 | $3.46 |
| 78.12 | 78.12 | 78.12 | 78.12 | $15.97 |
| 25.31 | 25.31 | 152.03 | 152.03 | $8.22 |
| 468.75 | 468.75 | 468.75 | 468.75 | $0.44 |
| 1.46 | 1.46 | 1.46 | 1.46 | $855.77 |
| 0.47 | 0.47 | 2.84 | 2.84 | $440.21 |
| 8.75 | 8.75 | 8.75 | 8.75 | $23.77 |
| 10.02 | 10.02 | 10.02 | 10.02 | $124.54 |
| 3.25 | 3.25 | 19.50 | 19.50 | $64.06 |
| 60.13 | 60.13 | 60.13 | 60.13 | $3.46 |
| 78.12 | 78.12 | 78.12 | 78.12 | $15.97 |
| 25.31 | 25.31 | 152.03 | 152.03 | $8.22 |
| 468.75 | 468.75 | 468.75 | 468.75 | $0.44 |

## Appendix G. Evaluation of Steady State

The graphs that follow give visual information about the starting condition problem resulting from data bias at the start-up of the model. Actual values found to indicate when the time bias was eliminated from the model data are given in each treatment graph. Each graph represents 8000 time units roughly equating to 650 years. Every 48 months data was collected in the model yielding a sample size of 167.

The initial bias was eliminated using a method developed by Shruben, Singh and Tierney. A more in-depth discussion of the procedure is available in a book written by Jack P.C. Kleijnen, Statistical Tools for Simulation Practitioners.

A critical t-statistic was compared to the individual t-statistics to decide when the start-up conditions no longer had statistics. Using Shruben, Singh and Tierney's equation for calculating degrees of freedom;

$$\text{degrees of freedom} = \left(\frac{n}{2}\right) - 1 \Rightarrow 83\,\text{df} \quad \text{with } \alpha = .005, \text{ and df} = 83; \text{ the}$$

value was not listed in the table of t-statistics. For the purposes of this study it was decided to use $\alpha = .005$, and

df = 60. Using df = 60 the researchers obtained a conservative value and the critical value of t was established as |3.4|. The time associated with |3.4| was found for each treatment and the value is given in each treatment graph.

The graphs reflect that although stationary, average on-hand inventory variance fluctuated greatly while average annual orders variance remained small.

**Treatment One**

Evaluation of Steady State

Initialization bias eliminated at time = 624

**Treatment Two**

Evaluation of Steady State

Initialization bias eliminated at time = 576
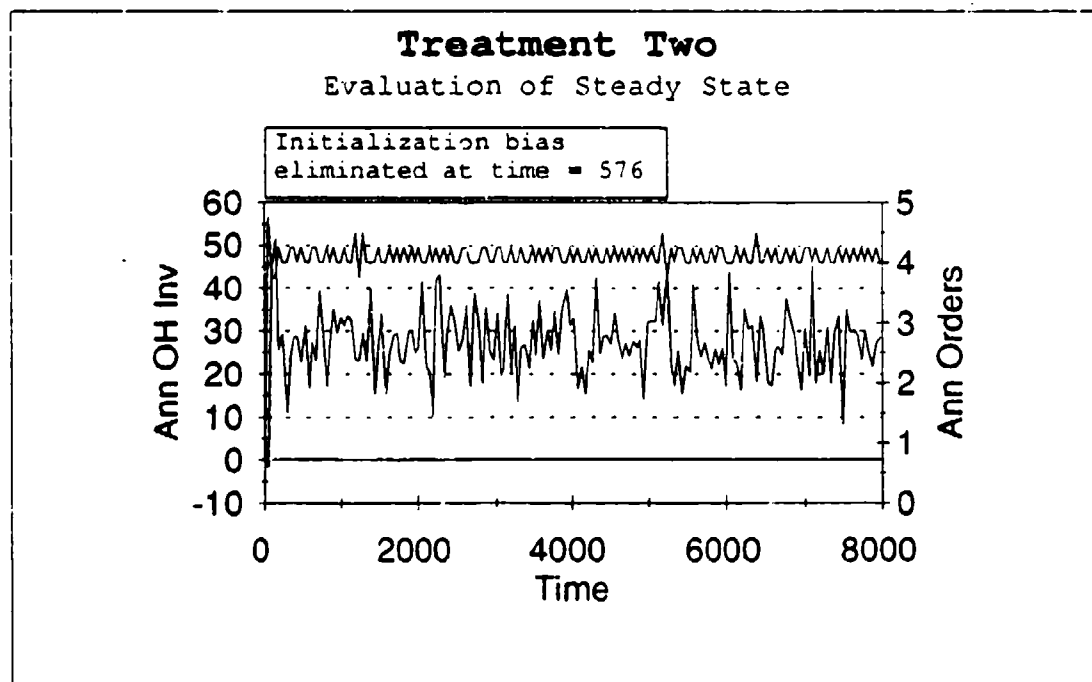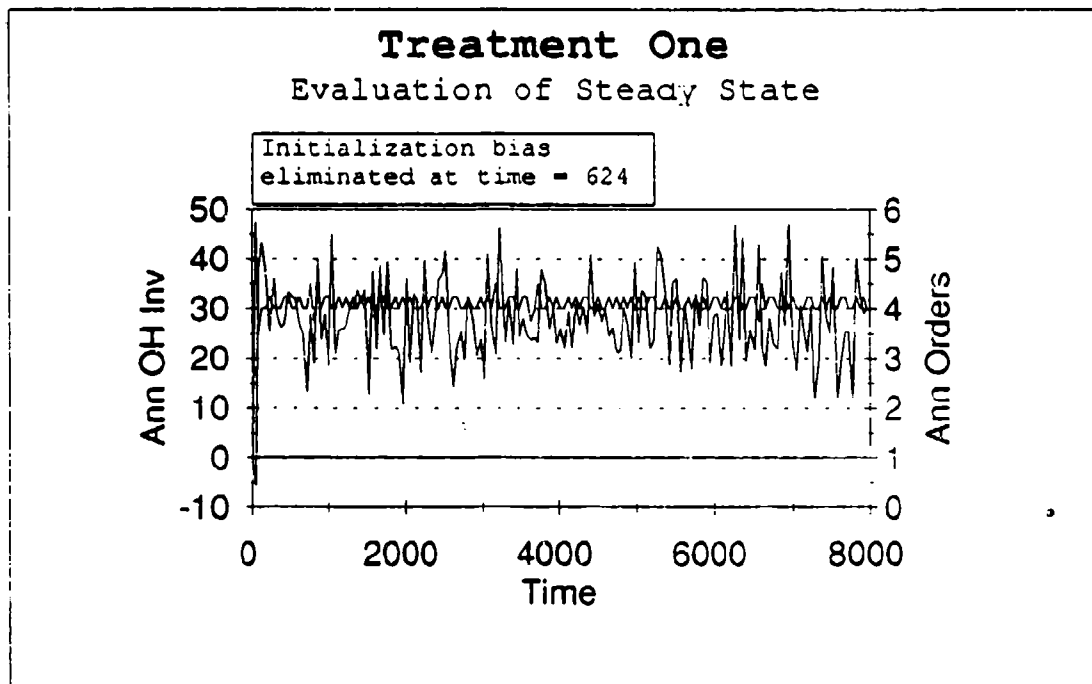
# Treatment Three

## Evaluation of Steady State

Initialization bias
eliminated at time = 432
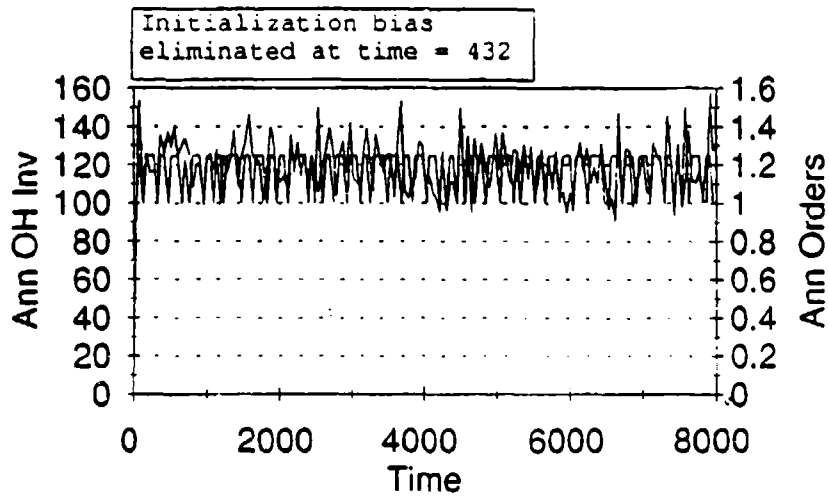


# Treatment Four

## Evaluation of Steady State

Initialization bias
eliminated at time = 960
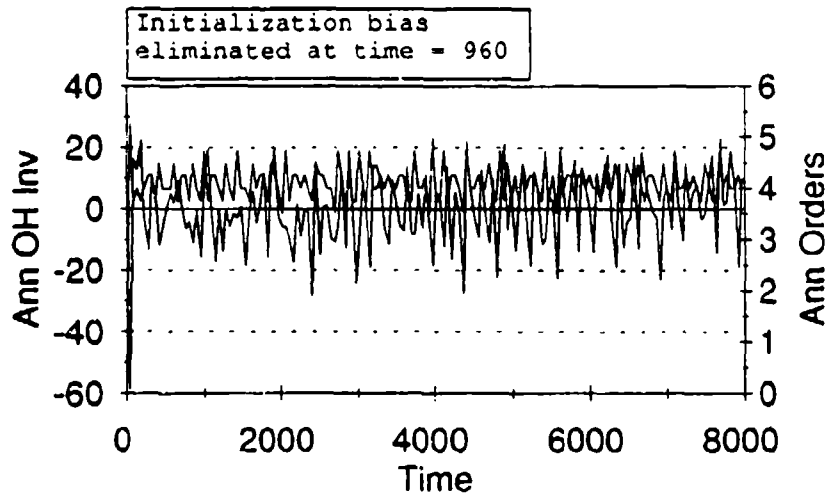
## Treatment Five
### Evaluation of Steady State

Initialization bias
eliminated at time = 864
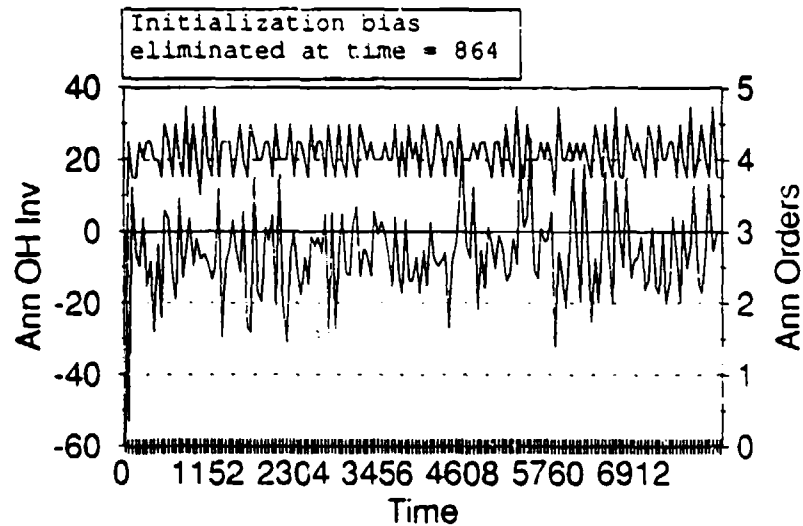


## Treatment Six
### Evaluation of Steady State

Initialization bias
eliminated at time = 432
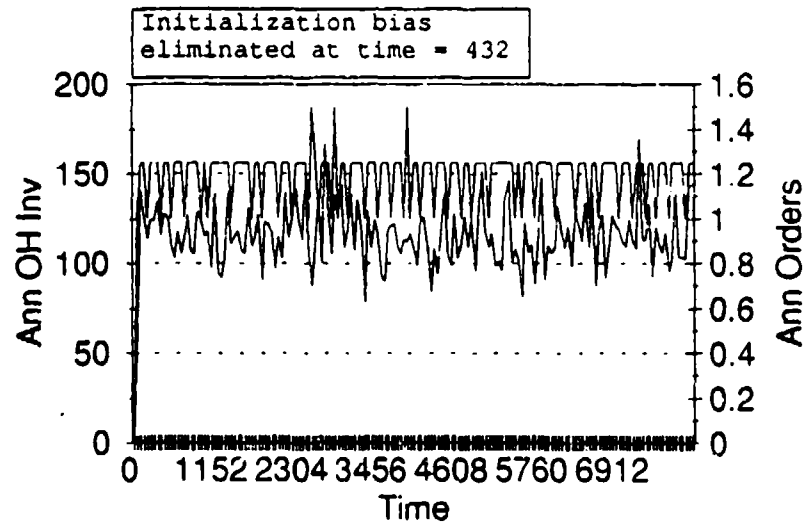
Treatment Seven
Evaluation of Steady State

Initialization bias
eliminated at time = 480
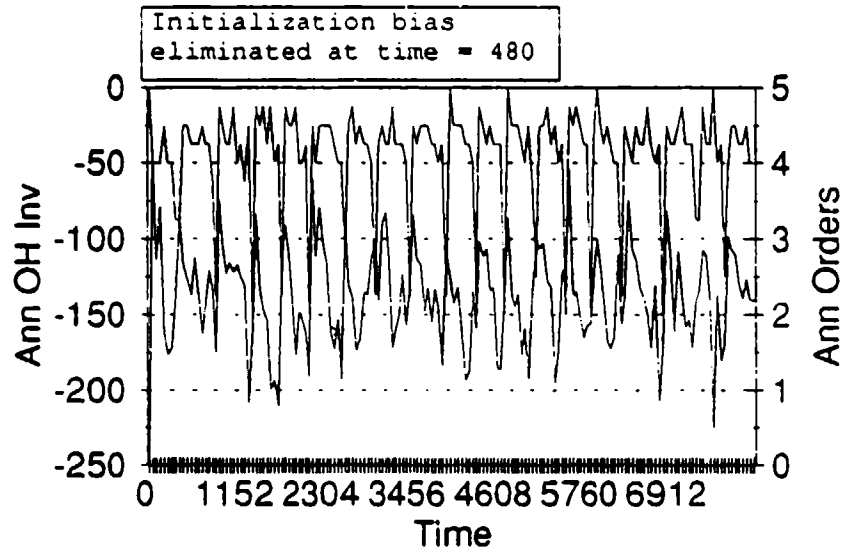


Treatment Eight
Evaluation of Steady State

Initialization bias
eliminated at time = 480

118
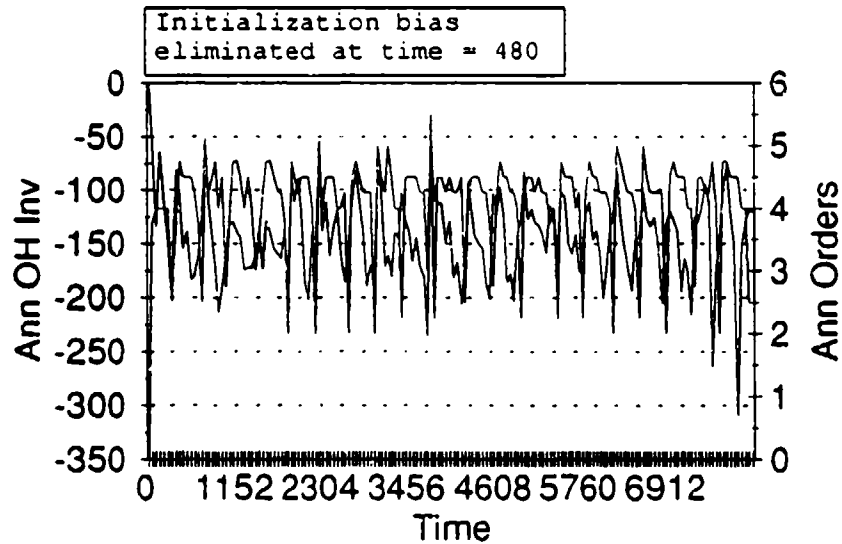
**Treatment Nine**

Evaluation of Steady State

Initialization bias
eliminated at time = 672
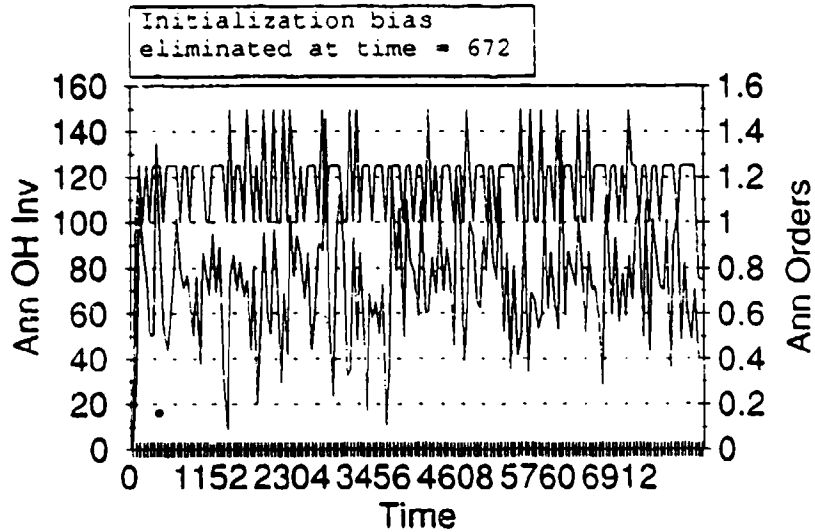


**Treatment Ten**

Evaluation of Steady State

Initialization bias
eliminated at time = 768
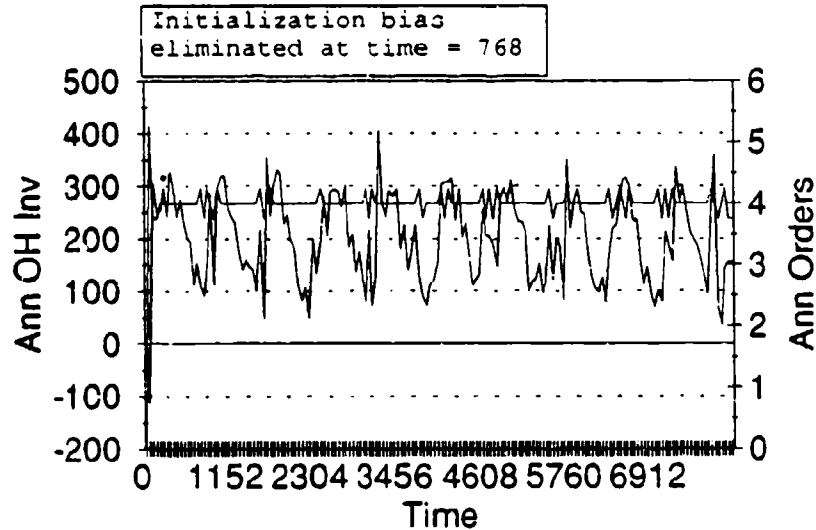
**Treatment Eleven**

Evaluation of Steady State

Initialization bias eliminated at time = 624
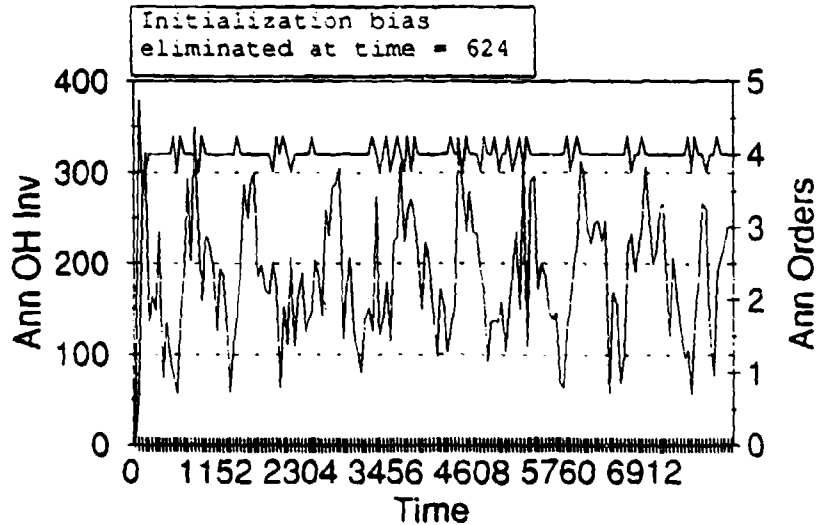


**Treatment Twelve**

Evaluation of Steady State

Initialization bias eliminated at time = 384

120
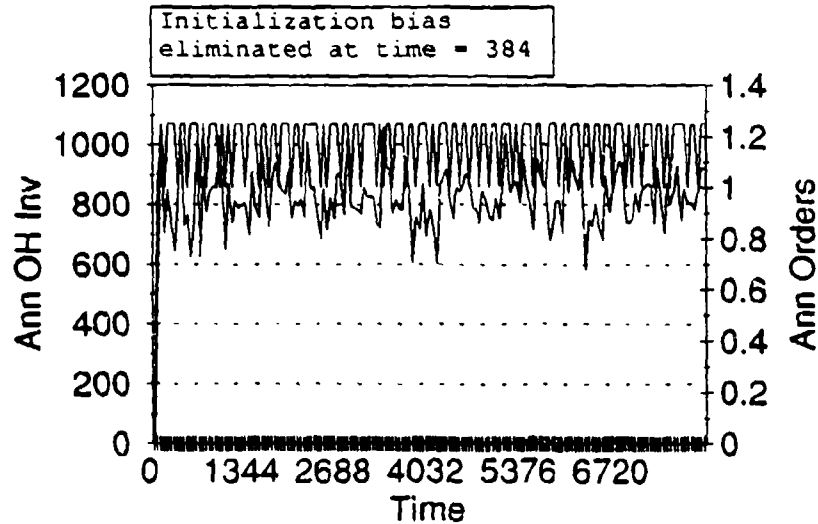
Treatment Thirteen

Evaluation of Steady State

Initialization bias eliminated at time = 816
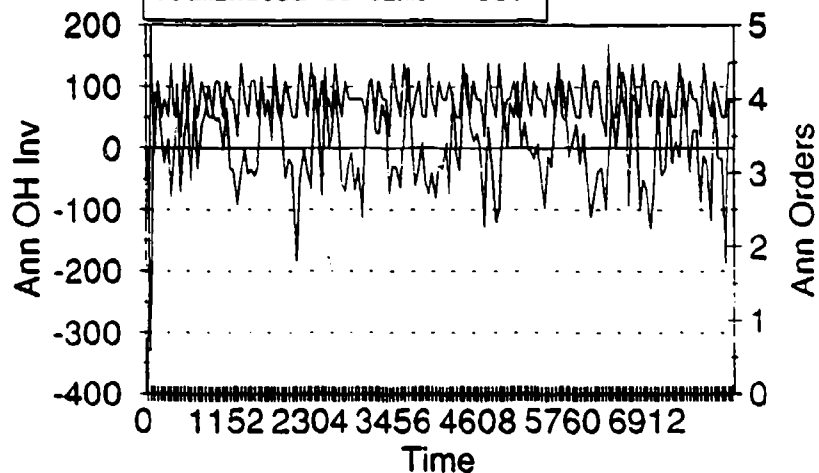


Treatment Fourteen

Evaluation of Steady State

Initialization bias eliminated at time = 768
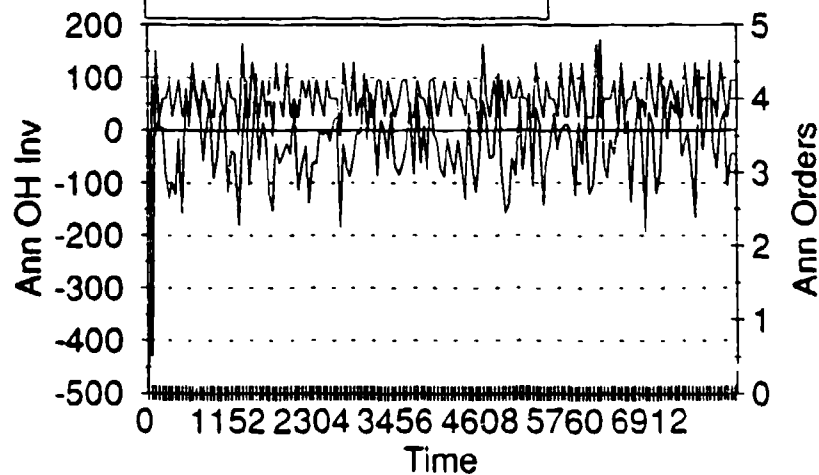
## Treatment Fifteen
### Evaluation of Steady State

Initialization bias
eliminated at time = 432
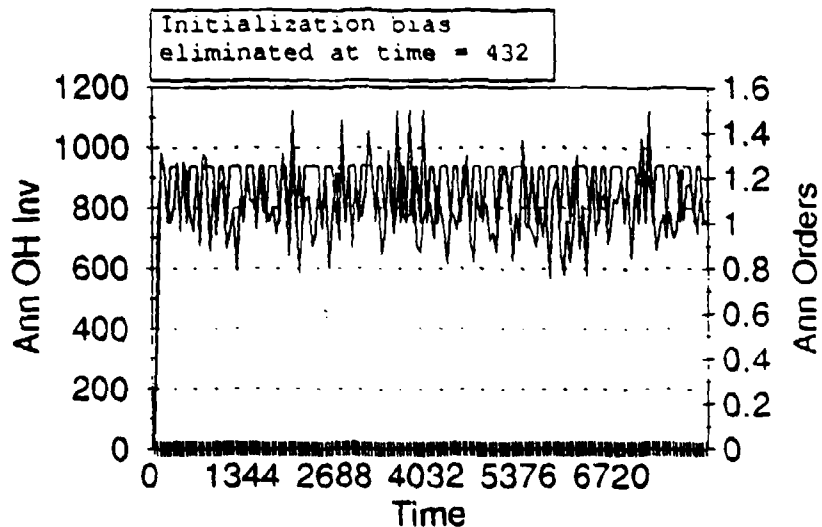


## Treatment Sixteen
### Evaluation of Steady State

Initialization bias
eliminated at time = 432
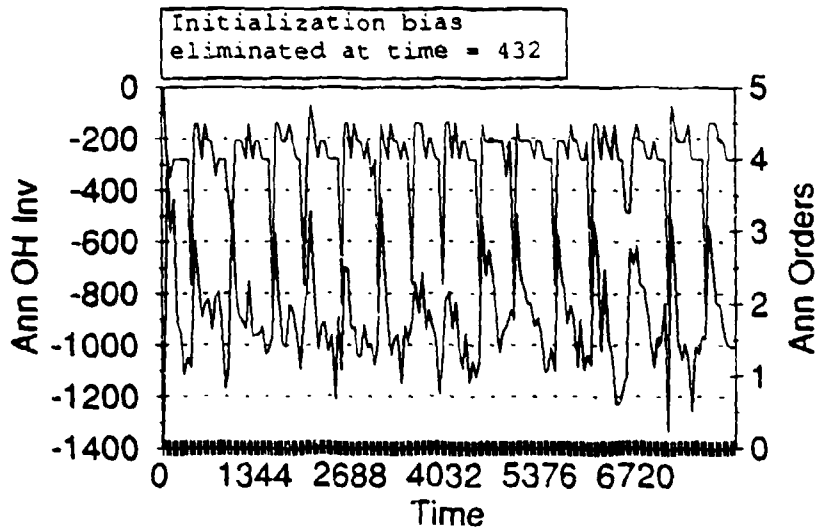
**Treatment Seventeen**

Evaluation of Steady State

Initialization bias
eliminated at time = 432
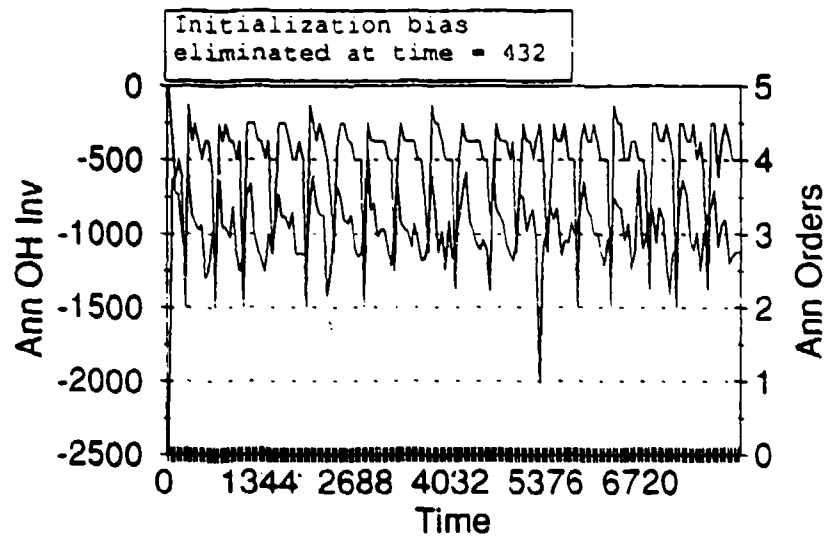


**Treatment Eighteen**

Evaluation of Steady State

Initialization bias
eliminated at time = 720
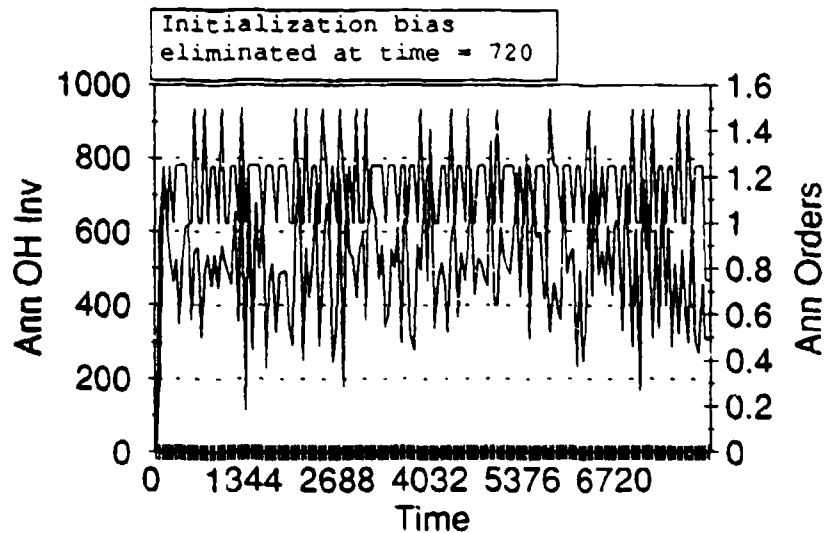
**Treatment Nineteen**
Evaluation of Steady State

Initialization bias eliminated at time = 1008
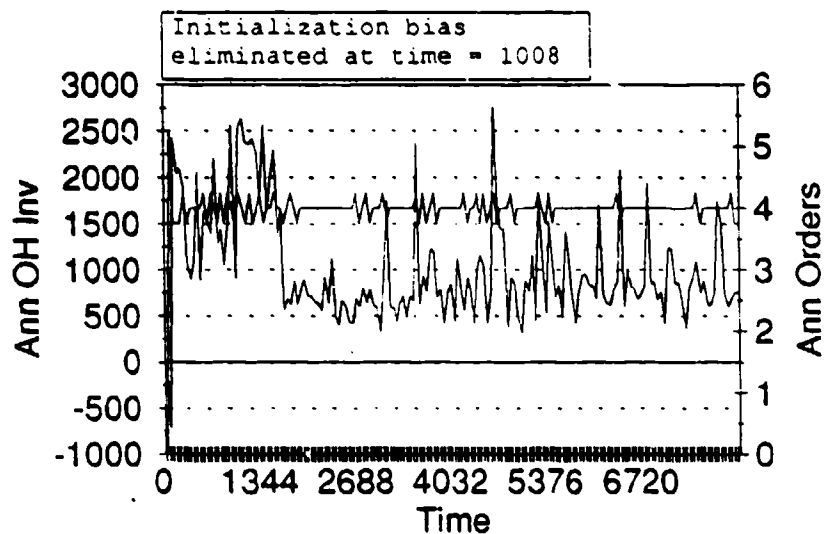


**Treatment Twenty**
Evaluation of Steady State

Initialization bias eliminated at time = 1056
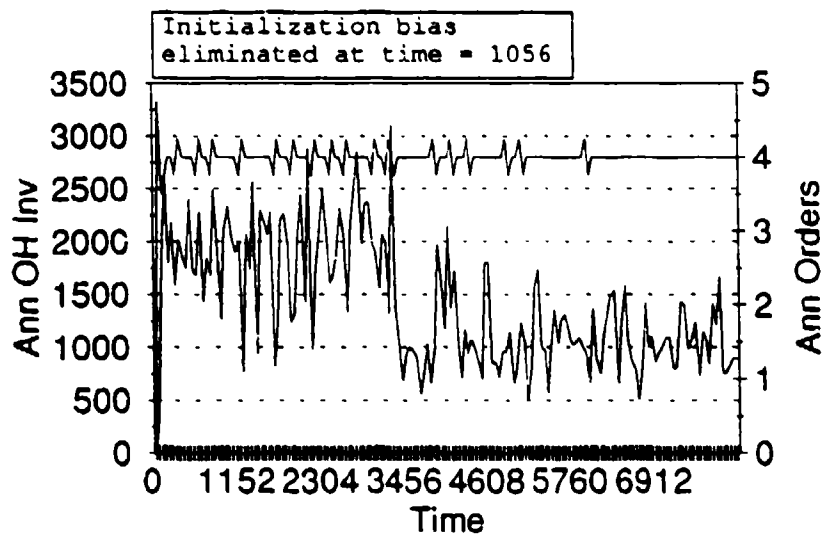
**Treatment Twenty-One**
Evaluation of Steady State

Initialization bias eliminated at time = 432
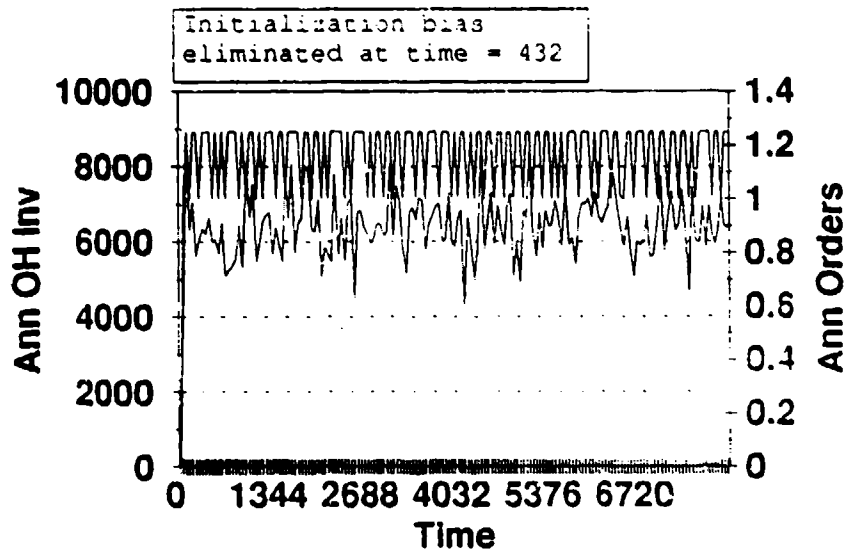


**Treatment Twenty-Two**
Evaluation of Steady State

Initialization bias eliminated at time = 816

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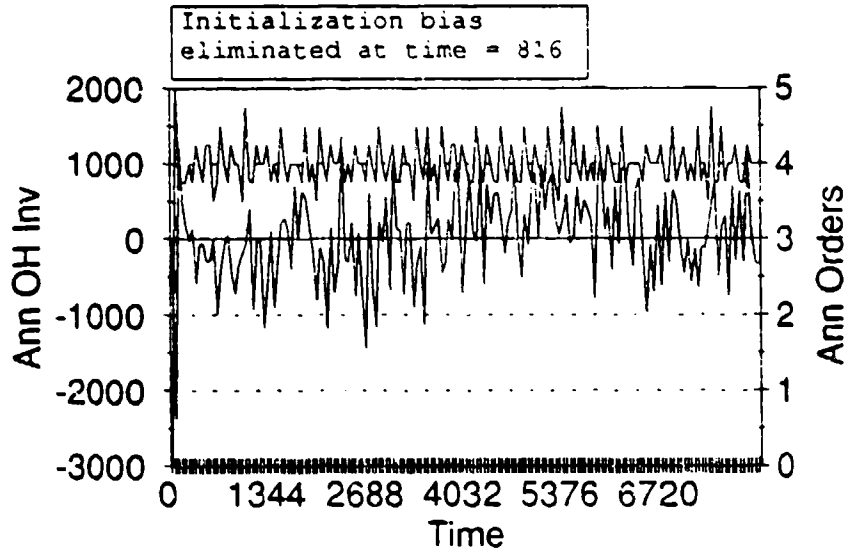
**Treatment Twenty-Three**
Evaluation of Steady State

Initialization bias
eliminated at time = 912
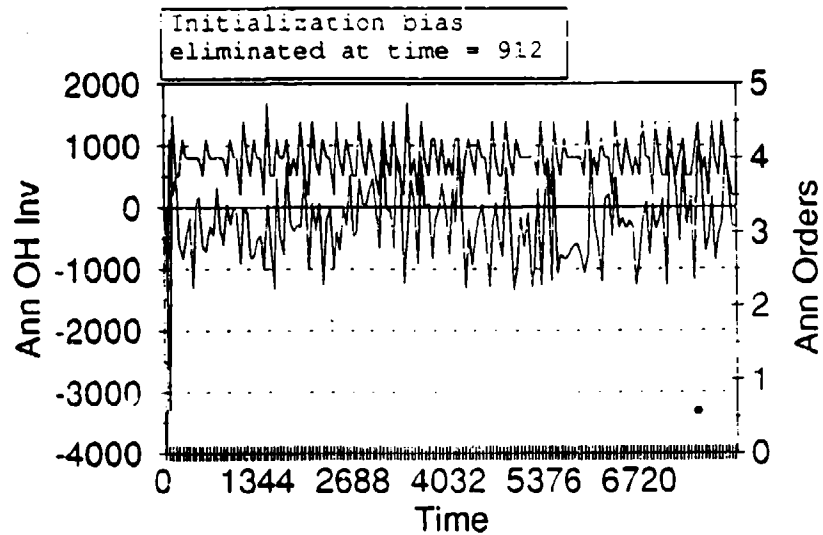


**Treatment Twenty-Four**
Evaluation of Steady State

Initialization bias
eliminated at time = 384
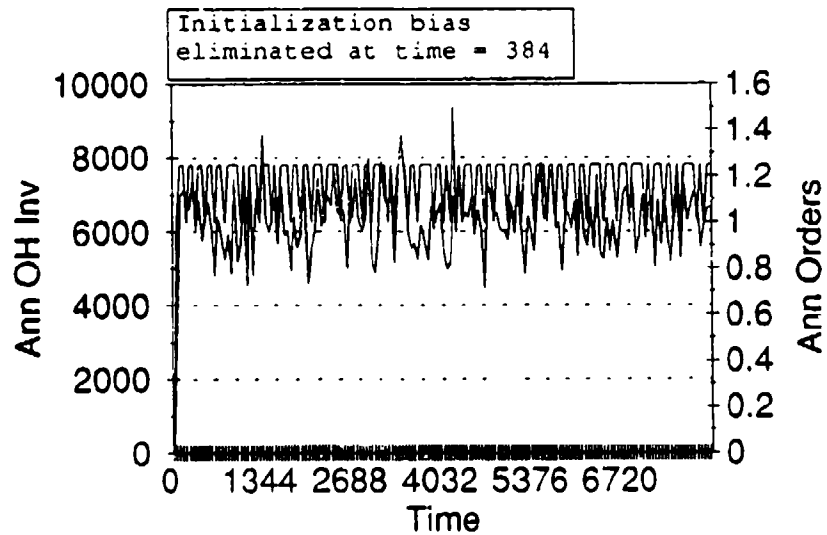
Treatment Twenty-Five
Evaluation of Steady State

Initialization bias eliminated at time = 432
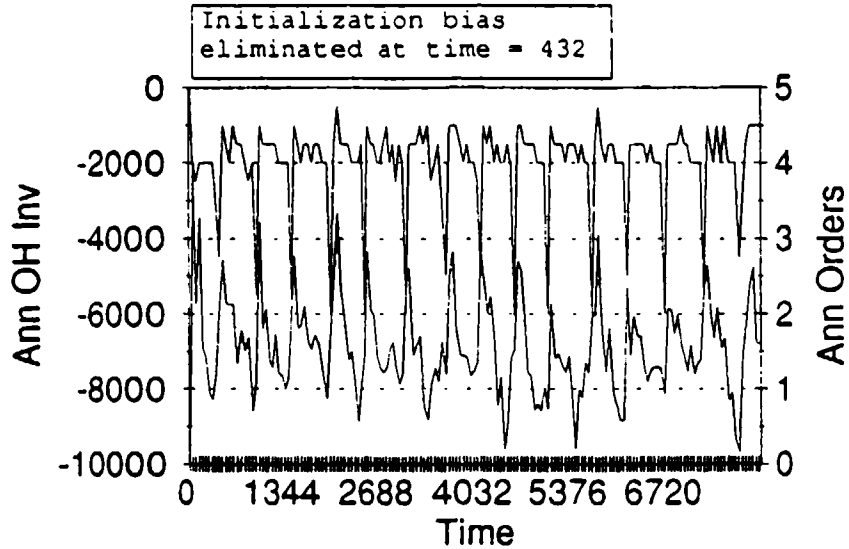


Treatment Twenty-Six
Evaluation of Steady State

Initialization bias eliminated at time = 432
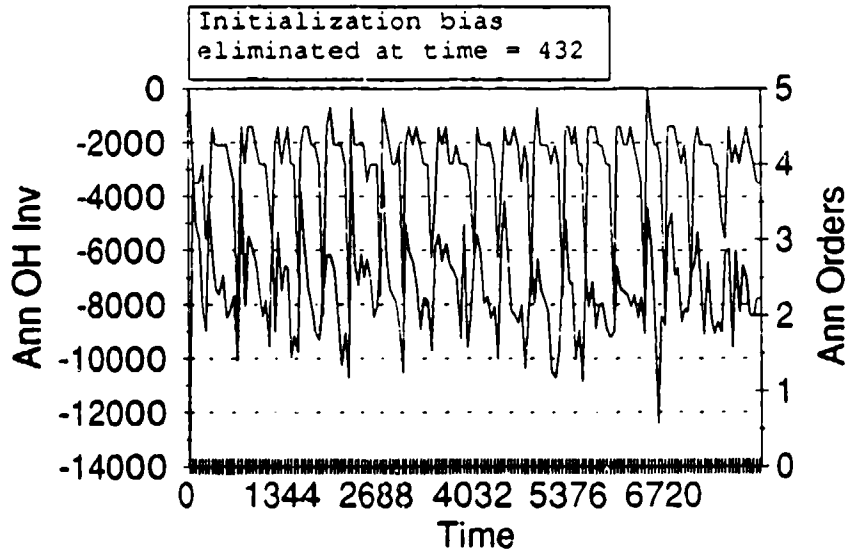
Treatment Twenty-Seven
Evaluation of Steady State

Initialization bias
eliminated at time = 672
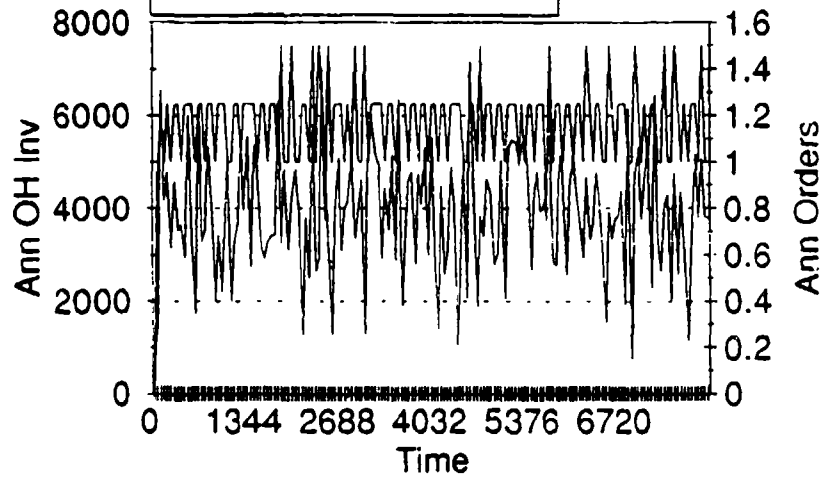
## Appendix H: Average Annual On Hand and
## Pre-Replenishment Inventory Levels


The graphs on the following pages represent the effects of varying demand, demand pattern and lead time.    Each graph includes nine treatments, showing the mean values from 30 model runs for all treatments.    Shown are graphs of average annual on hand inventory levels and pre-replenishment inventory levels.    The graphs include a text box to indicate when a change of scale occurs.

# Average Annual On Hand Inventory
## Annual Demand Level = High

**High Demand Pattern**

(bar chart: Avg Annual Inv vs Lead Time — High, Med, Low; y-axis from -600 to 1000)

**Medium Demand Pattern**

(bar chart: Avg Annual Inv vs Lead Time — High, Med, Low; y-axis from -500 to 1000)

**Low Demand Pattern**

(bar chart: Avg Annual Inv vs Lead Time — High, Med, Low; y-axis from -500 to 1000)

# Average Annual On Hand Inventory
## Annual Demand Level = Medium

**High Demand Pattern**

(bar chart: Avg OH Inv vs Lead Time — High, Med, Low; y-axis from -500 to 1000)

**Medium Demand Pattern**

(bar chart: Avg OH Inv vs Lead Time — High, Med, Low; y-axis from -500 to 1000)

**Low Demand Pattern**

(bar chart: Avg OH Inv vs Lead Time — High, Med, Low; y-axis from -500 to 1000)

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# Average Annual On Hand Inventory

## Annual Demand Level = Low

**High Demand Pattern**



**Medium Demand Pattern**



**Low Demand Pattern**



The scale for this graph is an order of magnitude different than the scales for the two graphs on the previous page.

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Pre-Replenishment Inventory
Annual Demand Level = High
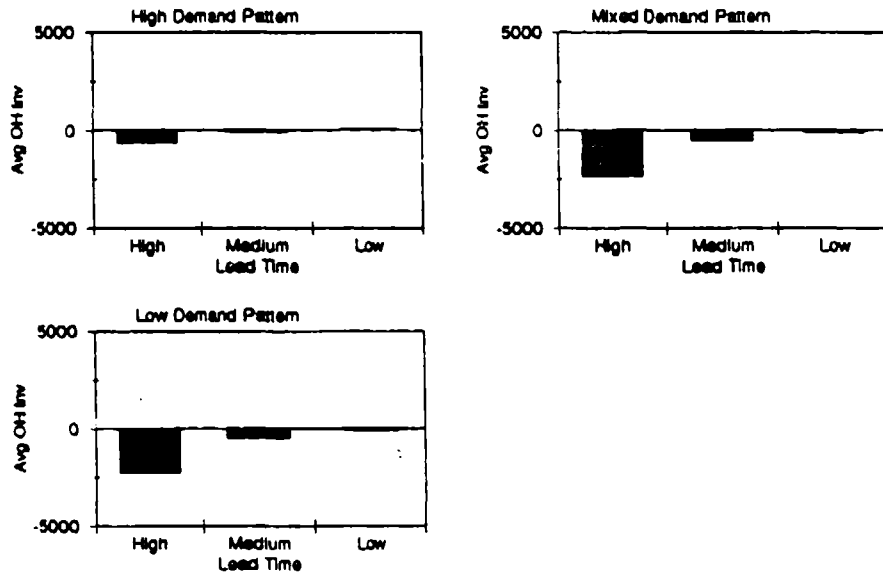


Pre-Replenishment Inventory
Annual Demand Level = Medium
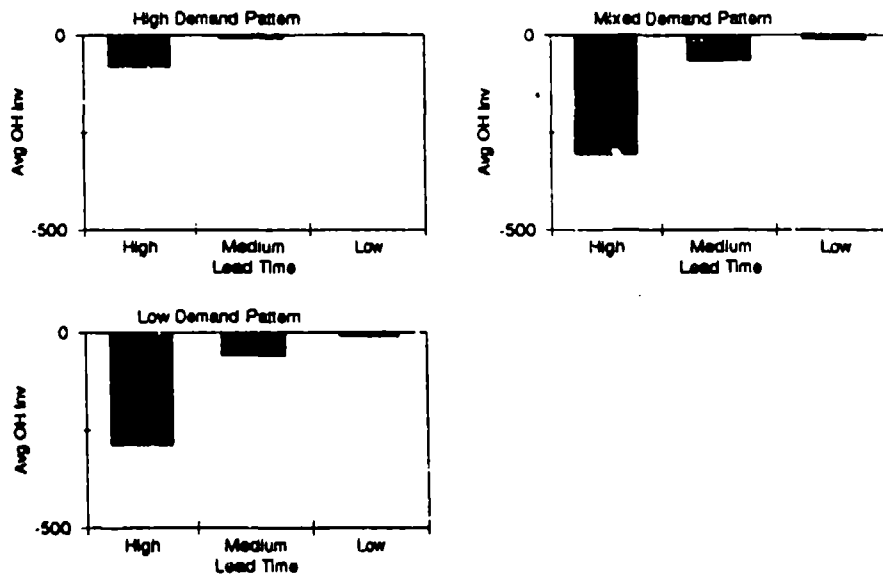
Pre-Replenishment Inventory
Annual Demand Level = Low
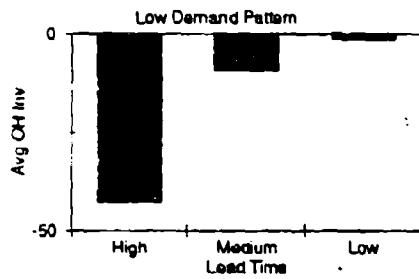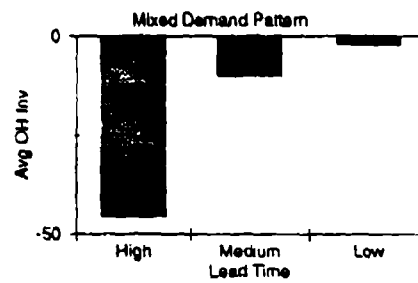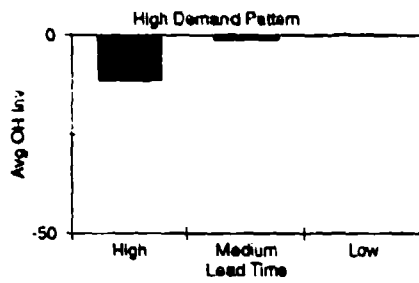
DLA T-Value Comparison

| Holding | Costs Ordering T=69 | Ordering T=74 |
|---|---|---|
| 13% | $77.37 | $88.99 |
| 14% | $83.32 | $95.83 |
| 15% | $89.27 | $102.68 |
| 16% | $95.22 | $109.52 |
| 17% | $101.17 | $116.37 |
| 18% | $107.12 | $123.21 |
| 19% | $113.07 | $130.06 |

## Holding to Ordering Costs
### Given DLA T-Values 69 and 74
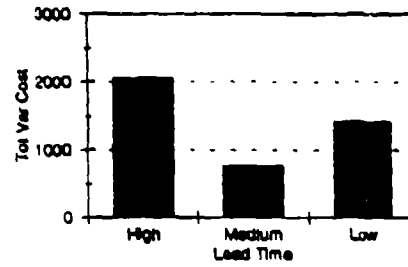


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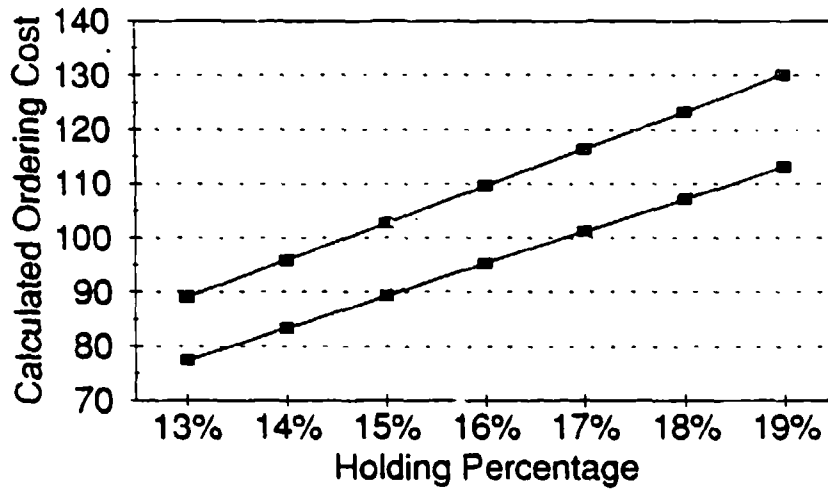
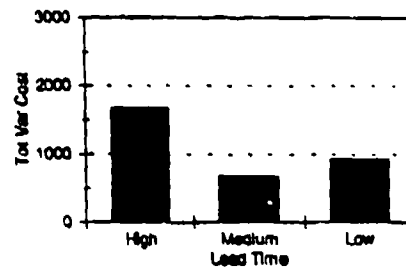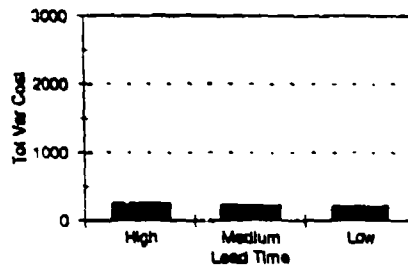# Total Variable Cost
## Annual Demand Level = High
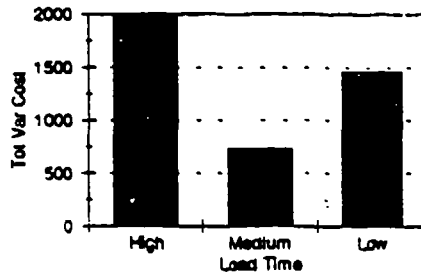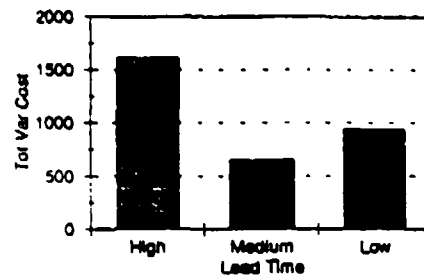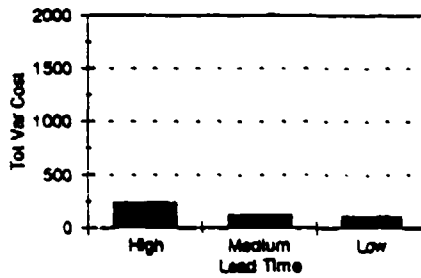


# Total Variable Cost
## Annual Demand Level = Medium

Total Variable Cost
Annual Demand Level = Low

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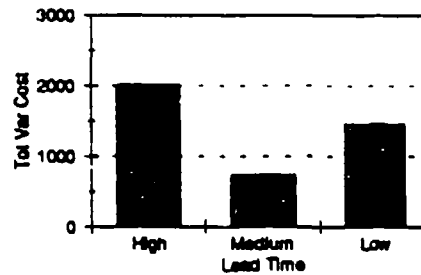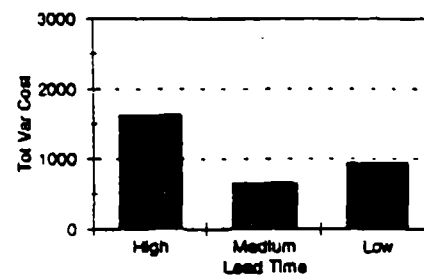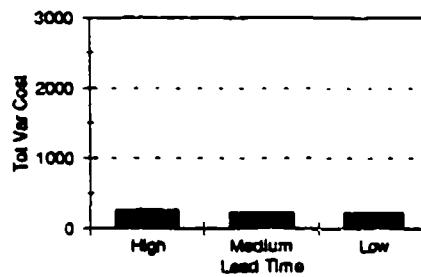
## Appendix I. Future Research

Total variable cost is made up of a holding cost component, an ordering cost component, and a cost to backorder component. The Classic EOQ normally does not consider the cost to backorder in its calculations. It is necessary to include it for the purpose of this research. Many of the average on-hand inventory values are negative for treatments. This would indicate that, on average, there are always outstanding customer demands that can not be filled or that the inventory center has to support customers constantly from safety stock. Given this, the holding cost would be zero. If negative values are taken to be customer backorders, the model reveals a situation where nothing is ever held on the shelf but is instead only ordered after the customer orders from the inventory center first. Total variable cost might look very good in this situation if the cost of carrying the customer backorder is not considered. It can be guaranteed that any business that did not consider the cost of the backorder would not be in business very long. If negative average values are observed, it indicates that safety level is constantly being used, so additional stock must be held to bring the model back up to its expected 50% service level. For this study, a cost of a backorder will be calculated and included in the total variable cost. To accomplish this, the average pre-replenishment inventory will be treated as the number of

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average backorders. An imputed cost of a backorder will be established and applied to the total variable cost. In this manner, a more realistic look at what the inventory policy costs the organization is generated. This appendix shows the method used for calculating the backorder cost, as well as the calculated values.

Further concerns about the method for calculating backorder costs must be addressed. The EOQ model assumes a normal distribution of demand during lead time. For the purpose of calculating the backorder cost, this study will make the same assumption. Given that no safety stock was carried in the simulation model, one would expect the average pre-replenishment inventory position to be zero and the customer service level to be 50%. Based on the values for pre-replenishment inventory, shown in Table 9 earlier, it seems that the distribution during lead time is not normal under lumpy demand conditions. By assuming normality, the estimate for total variable cost will be conservative and yield an understatement of the actual total variable cost.

The results of the total variable cost calculations are shown in Table 11, below. Appendix H shows this data graphically.

Table 11.

## Total Variable Cost Calculated for All Treatments

| Annual Demand | Lead Time | Demand Pattern | | |
|---|---|---|---|---|
| | | High | Mixed | Low |
| High | High | 240.12 | 1611.14 | 1998.81 |
| | Medium | 121.27 | 650.16 | 734.95 |
| | Low | 110.96 | 936.07 | 1455.91 |
| Medium | High | 257.59 | 1621.43 | 2008.03 |
| | Medium | 231.49 | 652.36 | 731.99 |
| | Low | 223.97 | 934.88 | 1449.76 |
| Low | High | 256.79 | 1673.72 | 2058.93 |
| | Medium | 231.21 | 675.59 | 756.42 |
| | Low | 224.08 | 922.35 | 1415.61 |

Annual demand, demand pattern, and lead time have definite effects on the total variable costs associated with the DLA inventory policy under lumpy demand. As annual demand moves lower and lower, the total variable cost gets larger. This seems contradictory to intuition but the data shows there are some efficiencies that go along with ordering the larger economic order quantities that larger annual demands would dictate. Also, as the demand pattern factor varies from the high quantity, infrequent level to the mixed level and on to the low quantity, frequent demand level, the total variable cost gets larger. This makes sense because the more frequently orders are placed on the inventory center, the more frequently the inventory center has to order to satisfy that demand. Lead time provides some interesting results, too. For the high demand pattern, a lower lead time corresponds to a lower total variable cost. For the mixed and low demand patterns, however, the

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medium lead time provides for the lowest total variable cost with the low lead time being the next cheapest and high the lead time the most expensive. This is completely counter to the current beliefs and teachings about lead time. Lower lead time is supposed to mean lower costs. Under the EOQ model, however, a high lead time drives the backorder component of total variable cost higher. A low lead time, on the other hand, drives a greater amount of material on the shelf and therefore a greater holding cost. The medium lead time yields a compromise between these two extremes and the lowest total variable cost.

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## Vita

Captain William 'Steve' Long was born 7 June 1967 in Newberry, South Carolina. He attended Newberry High School, Newberry, South Carolina, and graduated in 1985. In 1989, Captain Long graduated from The University of South Carolina with a Bachelor of Science degree in Mathematics and earned a commission as a graduate of Air Force ROTC.

Captain Long was formerly stationed at Oklahoma City Air Logistics Center, Tinker Air Force Base, and served as the Deputy Chief of C-135 Scheduling and Materiel. He then moved to the 552nd Airborne Warning and Control Wing Tinker AFB, where he served as the Materiel Liaison Officer for the E-3 weapon system. Captain Long then served an overseas tour to Osan AB, Korea where he served as Operations Support Flight Chief and Materiel Management Flight Chief until he entered the Air Force Institute of Technology, School of Logistics and Acquisition Management in May 1993.

Steve and his wife Tonya, were married on 1 August 1987 and have a son Andrew, age 5, and a daughter Kathryn, age 3.

Permanent Address:

Rt #1, Box 364 D
Prosperity, SC 29127

# Vita

Captain Douglas H. Engberson was born on 6 September 1963 in Alpine, Utah. He attended American Fork High School in American Fork, Utah, and graduated in May 1981. Douglas served a Mission for The Church of Jesus Christ of Latter Day Saints to Sevilla, Spain from 1982 to 1984. In 1989, Captain Engberson graduated from the University of Utah with a Bachelor of Science degree in Geography and earned a commission as a graduate of Air Force ROTC.

Captain Engberson is a former Transportation Officer, and was last assigned to the 12th Transportation Squadron, Randolph AFB, Texas. Captain Engberson entered the School of Logistics and Acquisition Management in May 1993 and graduated in September of 1994. He received a follow-on assignment to the 436th Supply Squadron, Dover, Delaware.

He and his wife Linda were married in the Jordan River Temple on 11 November 1989, have a son Devin, age 3, and a daughter Heather, age 1.

Permanent Address:

516 North Grove Drive

Alpine, UT 84004

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This project determined the impact of stationary but non-continuous demand levied in a multi-echelon system. Specifically discussed is how this "lumpy" demand affected the Defense Logistics Agency, Defense Electronics Supply Center in its computed inventory levels and total variable costs. To determine the impact of "lumpy" demand, data was extracted from the Defense Logistics Agency, Defense Electronics Supply Center Dayton, Ohio. Based on patterns of demand and distributions, the authors constructed a SLAM II model that depicted "lumpy" orders being received at the Defense Logistics Agency. The SLAM II model was constructed for the proposed system and simulation runs were conducted using demand distributions gathered from the sample data set. These runs indicate that "lumpy" demand does impact negatively total variable cost and on-hand inventory levels. It is recommended the Defense Logistics Agency consider other lot sizing techniques or look into a Distribution Resource Planning model to improve overall system inventory levels and total variable costs.

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